AFIT/GEE/ENV/95D-10

COMPARISON OF GRAVEL SUBSTRATE VS SOIL SUBSTRATE FOR THE CONSTRUCTION OF AN EXPERIMENTAL FEN

THESIS

Carolyn S. Langley
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COMPARISON OF GRAVEL SUBSTRATE VS SOIL SUBSTRATE FOR THE CONSTRUCTION OF AN EXPERIMENTAL FEN (WETLAND)

Carolyn S. Langley
Captain, USAF

Presented to the Faculty of the Graduate School of Engineering
of the Air Force Institute of Technology
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Engineering and Environmental Management

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Abstract

Under the Clean Water Act Section 404 of 1972 and 33 CFR 320-330 and 40 CFR 230 moderate the destruction of wetlands by the Air Force to make way for other uses. To obtain a permit for a design or construction project which affects a wetland, the Air Force must agree to create new wetlands, or replace lost wetland acreage through wetland creation or restoration. The Air Force is interested in building "successful" wetlands as inexpensively as possible. It has been common practice to use hydric soil, which often had to be hauled in, as the substrate at the restored site to ensure vegetative success of the site. However, this project constructed a fen (wetland) 32m x 15.5m to experimentally compare the impact on vegetation of unsorted gravel till substrate versus hydric soil substrate. A fen is a groundwater driven wetland with a circumneutral pH and little to no standing water. Initial indicate that the hydric soil did better support vegetation, but the gravel substrate was functional. The vegetation on the gravel substrate is expected to catch up to that on the soil substrate in time.

1.0 INTRODUCTION

1.1 BACKGROUND

Wetlands have been perceived differently as more has been learned about them. Early European settlers of North America viewed wetland areas as unpleasant, unhealthy wastelands to be drained and converted to useful agricultural land. We have learned in recent decades that wetlands perform many functions including: nutrient removal and transformation, sediment and toxicant retention, shoreline stabilization, floodflow alteration, aquatic diversity and abundance, wildlife habitat, ground water recharge, and production export (Marble, 1992). The Federal Manual (Environmental Protection Agency, 40 Code of Federal Regulations 230.3 and CE, 33 CFR 328.3) defines wetlands as: "Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions."

Wetlands provide critical habitat. Although wetlands represent only an estimated five percent (Di Silvestro, 1987) of the total United States land area, 26% of the plants and 45% -50% of the animals (Hammer, 1992; Mitsch, 1993) listed as threatened or endangered under the Endangered Species Act are directly or indirectly dependent on wetlands for survival. Some 900 species of wildlife in the U.S. require wetland habitats at some stage in their life cycle (Hammer, 1992). Two-thirds of the 10 to 12 million

waterfowl in the lower 48 states reproduce in the prairie potholes of the Midwest, and millions of ducks winter in the bottomland hardwoods of the south-central states (Barton, 1985). One third of North American bird species rely directly on wetlands for some resource. The diverse habitats available in U.S. wetlands contain 190 species of amphibians, 270 species of birds, and over 5000 species of plants (Barton, 1985; Hammer, 1992). Over fifty percent of the marine sport fish caught in the United States depend on wetland estuaries, and roughly two-thirds of the major U.S. commercial fish depend on estuaries and salt marshes for nursery or spawning grounds (Barton, 1985).

For years, society's low opinion of wetlands was demonstrated by public policies. Prior to the mid 1970's, draining and destroying wetlands for developmental reasons was encouraged by many U.S. government policies including the Swamp Lands Acts of 1849, 1850, and 1860 (Mitsch, 1993; Shaw and Fredine, 1956). Approximately half of the U.S. wetlands have been lost (Patrick, 1994). Several of our large cities and many major airports are situated entirely, or in part, on former wetlands (Mitsch, 1993). States such as California, Iowa, and Ohio retain only 10 percent of their original wetland expanses (Kusler, 1994), while a total of 22 states have lost 50 percent or more of their original wetland areas (Dahl, 1990). These losses continue despite protection under Section 404 of the Clean Water Act (CWA) of 1972. Current wetland losses have been estimated to be between 300,000 to 485,000 acres per year (Schneller-McDonald, 1987). Of the original 221 million acres believed to have existed in the contiguous United States in 1780, only about 53 percent of that or 104 million acres were estimated to remain in 1989.

The considerable country-wide interest in slowing wetland conversion is reflected in current legislation governing wetlands. National policy has undergone several changes. In 1977, President Carter signed into law Executive Order 11990, Protection of Wetlands, requiring permits and impact analysis for any expansion or development into wetland areas. The 1985 farm bill (the Food Security Act of 1985, Public Law 99-198) incorporated a "swampbuster" provision (Title XII, Subtitle C) that denies federal price supports, payments, certain loans, and other benefits to farmers growing crops on newly converted wetlands. The Tax Reform Act (P.L. 99-514) of 1986 repealed or altered several provisions of the tax code provided incentives for converting wetlands into cropland. Later, in 1990 President Bush signed an executive order calling for "no net loss" of wetlands, and expanding these permitting procedures. President Clinton announced a wetland initiative in August of 1993. It is these executive orders which drive the current policy of the Air Force.

Section 404 of the CWA of 1972 now moderates the destruction of wetlands to make way for agricultural, urban and industrial uses and is jointly administered by the United States Army Corps of Engineers (USACE) and the Environmental Protection Agency (EPA). Section 404 forbids discharge of dredged or fill material into "waters of the United States" without a permit from the USACE, thus affecting a wide array of construction activities in a range of aquatic habitats. Waters of the Unites States include lakes, rivers, streams, wetlands, prairie potholes, ponds, and other water bodies (33 CFR part 328 - 1989). The EPA has significant input into the wetlands program through guidelines laid out in Sections 401(b) and 404(c) of the 1972 CWA. Regulations

governing the Air Force's actions concerning wetlands are spelled out in 33 CFR 320-330 and 40 CFR 230. To obtain a permit for a design or construction project which affects a wetland, the applicant must agree to create new wetlands, or replace lost wetland acreage through wetland creation or restoration, usually at a ratio of 1.5 or more acres of new wetlands for every acre destroyed. Newly created wetlands may be used as credits for other projects.

The Army and the EPA signed a memorandum of agreement in February of 1990, clarifying the mitigation requirements of the CWA Section 404 guidelines (Gardner, 1990). The 404 program has helped slow wetland losses, however, extensive wetland losses have continued despite the legislation. Most wetlands loss in the past was due to agriculture. Agricultural conversion was the cause of 87 percent of wetlands losses from the mid-1950s to the mid-1970s (Tiner, 1984). While current losses due to agriculture are great, losses from the development of commercial and residential land are becoming more significant. The Water Resources Policy Act of 1985 (P.L. 99-662), applies to federal water projects and included authorization of $175 million for fish and wildlife mitigation at existing Corps water projects and strengthened mitigation requirements for future projects.

Other environmental laws governing the federal government and the Air Force, including the National Endangered Species Act, the Wilderness Act, and the Endangered Species Act, indirectly provide some additional protection for wetlands (Barton, 1987). The federal government holds an estimated 12.5 million acres of wetlands outside Alaska, about 13 percent of the United States' total, while the vast majority of the nation's

wetlands, roughly 65 million acres, are privately owned (Heimlich and Langner, 1986). The Department of Defense (DoD) is steward over 25 million acres (Brown, 1992) of real property and natural resources. This acreage includes some pristine or nearly pristine areas including wetlands which serve as a buffer for localized military activities and provide critical habitat. The Navy owns 1530 acres of wetlands (O'Neil, Lee, Cullinane, Gibeau, and Robertson, 1992). The Air Force owns an estimated 100,000 acres of wetlands in the United States (Waleski, 1995).

Mitigation is done to compensate for functions lost when natural wetlands are destroyed. Wetland creation projects are designed to create new wetlands while restoration projects restore historical wetlands. Enhancement of existing wetlands to improve or add functions and value is sometimes considered also a form of mitigation, depending on the state's interpretation of the CWA. For mitigation projects to be effective, they must become self-sustaining wetland systems that will ultimately replace the lost functions of the natural wetlands. Preservation of natural wetlands also plays an important role and is normally part of a mitigation package. It is in the best interest of conservation that we learn how to produce successful wetlands when losses are unavoidable.

1.2 GENERAL PROBLEM STATEMENT.

Mitigation can be a costly endeavor with highly unpredictable and often unsuccessful results. King and Bohlen (1994) found the average cost per acre for wetland

creation and restoration projects ranged from $1,000 to $779,000, with a maximum cost of $2,588,000/acre. While some successes have been documented in creating salt marshes (e.g., Seneca et al. 1976) and establishing fresh and saltwater marshes on dredged substrates by the USACE (e.g., Newling and Ladin, 1985), failures abound the literature. Race (1985) stated "...it is debatable whether any sites in San Francisco Bay can be described as completed, active or successful restoration projects at present." Josselyn and Buchholz (1984) concluded most California sites were not carefully monitored after project completion; therefore, long-term success or failure of these sites is not known. Since mitigation is so expensive, generally unpredictable, and often unsuccessful, it behooves us to study the success rate of previous wetland creations or restorations as well as the factors which influence success in constructed and natural wetlands.

Hydrology is the most important factor in the success of wetland restoration and creation projects (Lowry, 1990; Hammer, 1992; Mitsch and Gosselink, 1992; Pierce, 1993; Talbot and Tuttle, 1992). Soil type and chemistry and the establishment of appropriate vegetation are important factors in determining the success of natural or created wetlands. In fact, the Corps of Engineers (1987) system for delineating wetlands requires the hydric soil, special hydrologic conditions, and hydrophytic vegetation in order for an area to be considered wetland.

No consensus exists for the practice of establishing appropriate vegetation and ensuring the proper soil type and chemistry through the use of hydric soils. Constructed wetlands have often been sited on historical wetlands (previously drained or filled). Alternatively, hydric soils from present or historical wetlands were transported to the site

in either inoculant (small) or cover (large) quantities. Many experts strongly support such policies contending that these soils provide a valuable seed bank to help establish vegetation better and faster, in addition to making the substrate more similar to that of natural wetlands in critical chemistry and functional ways (EPA/600/R-92/150, 1992; Munro, 1991; Helliwell, 1989; Cutlip, 1984; Lowry, 1990; Hollands, 1990; Shuey, 1979; van der Valk, 1989). Others cite failures and drawbacks to these methods (Garbisch, 1993; Hollands, 1990; Maltby ,1987).

Practitioners have been fairly successful in creating freshwater marshes, but in bogs, fens, forested wetlands and other types of wetlands creation projects have been less successful, less researched, and even less often attempted (Lowry, 1990). Some wetland types including fens are being destroyed and being replaced with marshes or ponds (Roberts, 1993; Mitsch and Gosselink, 1993; Breen, 1993). This points to the need for additional research into the mitigation of fens.

1.3 SPECIFIC PROBLEM STATEMENT.

The wetlands we plan to examine are peat forming groundwater driven systems usually associated with calcium and carbonate rich aquifers, commonly referred to as fens. We intend our analysis and discussion to include fens, wet prairies, wet meadows, and

sedge meadows (Chapter 2). Fens are one of the least common wetland types by total remaining acreage, yet they have high species diversity and are homes to a large number of endangered plants and animals (Mitsch and Gosselink, 1986). Thus, they are a valuable wetland habitat which should be protected and recreated whenever possible (Amon, 1993). Although the hydrology of northern peatlands (fens and bogs) has been studied extensively in the former Soviet Union (e.g., Romanov, 1968; Ivanov, 1981), in the British Isles (Ingram et al., 1974; Ingram, 1982; Gilman, 1982) and in North America (e.g., Bay, 1967, 1969; Boelter and Verry, 1977; Verry and Boelter, 1979; Wilcox et al., 1986; Siegel, 1988); little research has been done on the restoration or creation of fens (Lowry, 1990; Breen, 1993). Prior to the establishment of two experimental fens in 1991 by Dr. Amon (1993), most experts were skeptical fens could be successfully created because of the unique hydraulic and geological conditions preceding and supporting natural fens.

The effect of soil type and planting mechanism on the success of vegetation in a constructed fen has not been well researched or documented to date. Engineers and scientists have generally assumed organic/hydric soil was necessary for the constructed or restored wetland site to be successful. This has been based largely on anecdotal evidence or more often purely on the belief that since organic/hydric soil best imitates the natural soil, it should be used. By constraining themselves to organic/hydric soils, builders have been forced to locate "new" wetlands on sites that were previously wetlands or to haul this soil in from other sources, at great expense and effort. Research is needed to test the requirement for this expense and effort

1.4 FOCUS QUESTIONS.

Overall Question. How does the use of mineral soil of gravel rich glacial till compare to Westland silty clay loam (a hydric or wetland soil) topsoil in effects on the growth of plants (success) in the growing season of a constructed fen?

Specific Questions.

Plant Height Data.

(1) Is there a difference in the growth of individual plant species from greenhouse stock planted in the mineral topsoil versus the Westland silty clay loam topsoil?

(2) Is there a difference in the growth of individual plant species from seed planted in the mineral topsoil versus the Westland silty clay loam topsoil?

(3) Is there a difference in the growth of plants transplanted from natural wetlands into mineral topsoil versus Westland silty clay loam topsoil?

(4) Is there a significant difference between the influence substrate type has on individual plant species' growth if the species are planted from seed versus transplanted from greenhouse stock?

Biomass Data.
(5) Does the dry weight of biomass samples vary significantly between the two substrates?

(6) Does the organic content determined from the biomass samples vary significantly between the two substrates?

(7) Does the phosphate content as determined from the biomass samples vary significantly between the two subtrates?

Water Chemistry Data.
(8) Is the water chemistry of the gravel substrate significantly different from that of the Westland silty clay loam substrate, specifically with regard to pH, iron, alkalinity, total hardness, calcium hardness, magnesium hardness, ammonia, sulfate, and phosphate?

(9) Is the water chemistry in the upper soil layer (0-6" depth)or in the lower soil layer (6-12" depth) significantly different on the gravel side versus the hydric soil side?

(10) Is there a relationship between the water chemistry on the two sides and growth of vegetation in the fen?

2.0 BACKGROUND/LITERATURE SEARCH

2.1 DEFINING CHARACTERISTICS OF WETLANDS.

A three-parameter approach to defining wetlands has been adopted by the United States Army Corps of Engineers (USACE)(1987)which requires the hydric soil, special hydrologic conditions, and hydrophytic vegetation. The 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands (1989 Manual) also characterizes wetlands based on these three criteria. According to the 1989 Manual, even when the vegetation criteria is not met, if both the hydric soils and wetland hydrology are present, then by definition the area also has hydrophytic vegetation, and is therefore considered to be a wetland. Thus, under this system farmed wetland is classified as wetland.

Vegetation is often the most challenging of the three parameters to evaluate but published listings of plants that occur in wetlands (obligate and facultative species) are available for guidance (eg Resource Management Group, 1992; USFWS, 1988). The USACE (1987) method considers the vegetation parameter to be hydric if greater than 50 percent of vegetative cover is adapted to wetland (saturated soil) conditions. The method categorizes plant species to be in one of five classes along a gradient from wetland to upland. The USACE (1987) defines obligate (OBL) wetland species as those always (>99% frequency) found with saturated soil conditions, while facultative wetland species (FACW) are those usually, but not always (>67% to 99% frequency) on saturated soils,

and facultative species (FAC) are those found on both wetlands and nonwetlands with equal frequency (33%-67%). Facultative upland species (FACU) are defined as usually (>67% to 99), but not always, found on upland sites, while upland species (UPL) are always (frequency >99%) found on nonwetland sites. A list of plant species and their affinity for wetland conditions, the "National List of Plant Species That Occur in Wetlands: 1988 National Summary," was published by the U. S. Fish and Wildlife Service (USFWS)of the Department of Interior (USFWS, 1988).

Scott, Slauson, Segelquist, and Auble (1989) studied the correspondence between vegetation and soils in wetlands and nearby uplands concluded that in general, hydric soils support hydrophytic plant communities, and nonhydric soils support upland communities. The study included 38 hydric and 26 nonhydric soils as recognized in the hydric soils list of the United States Soil Conservation Service (USSCS)(USDA, 1991). Only 10% of the hydric soils sampled support upland communities and only 15% of the nonhydric soils support wetland communities. A method that simplifies the complexity of soils and vegetation cannot be expected to represent accurately all the details of their interrelations. (Scott et al, 1989) A 1990 report summarizing a separate data set collected and compiled for USFWS, compiled for the USFWS, found almost complete agreement between hydric soils and hydrophytic vegetation in wetlands located in 11 states throughout the United States, confirming the validity of the USFWS national list of plant species occurring in wetlands (Segelquist, 1990).

Hydrology is usually the most imprecise and difficult to measure of these three delineation parameters. Evidence of flooding, plant physiological adaptation, or frequency

and duration of flooding for identification are components of most wetland hydrology definitions (USACE, 1987). In order to meet the wetland hydrology criteria, an area must be saturated to the surface or inundated at some point during an average rainfall year. Saturation to the surface is defined as:

> (1) In somewhat poorly drained mineral soils when the water table is less than 0.5 feet from the surface for at least one week during the growing season, or
>
> (2) In mineral soils that are poorly or very poorly drained (permeability < 6.0 inches/hour) the water table is less than 1.5 feet from the surface for at least one week during the growing season,
>
> (3) In more permeable (> 6.0 inches/hour) poorly drained or very poorly drained mineral soils, the water table is less than 1.0 foot from the surface for at least one week during the growing season, or
>
> (4) In poorly drained or very poorly drained organic soils, the water table is usually at a depth where saturation to the surface occurs more than rarely. (Hanley, 1990)

Inundation is defined as being ponded or frequently flooded with surface water for one week or more during the growing season. Legislation is currently under consideration which would increase this requirement to 21 days. Continual wetness of soils and saturation are not synonymous however. Saturation is a condition where all voids between soil particles are filled with water. Soils can be continually wet yet remain aerobic because water is moving through the soil profile (De Meo, 1989).

Hydric soils are those soils that are saturated, flooded, or ponded long enough to develop anaerobic conditions in their upper horizons (National Technical Committee for Hydric Soils, 1987). The 1989 Federal Manual for Identifying and Delineating

Jurisdictional Wetlands classifies soils as hydric if they meet the National Technical Committee for Hydric Soils criteria. These criteria are as follows:

> (1) all histosols except folists, or
>
> (2) soils in aquic suborders, aquic subgroups, albolls suborder, salorthids great group of Pell great groups of Vertisols that are: (I) somewhat poorly drained and where the water table is less than 0.5 feet from the surface for a significant period during the growing season, or (II) poorly or very poorly drained soils where either the water table is less than one foot from the surface for a significant period during the growing season for soils with a permeability greater than or equal to six inches per hour in all layers within 20 inches of the surface, or the water table is within 1.5 feet of the surface for a significant period during the growing season for soils with permeabilities less than six inches per hour in any layer within 20 inches of the surface, or
>
> (3) soils that are ponded continuously for at least seven days during the growing season, or
>
> (4) soils that are frequently flooded continuously for at least seven days during the growing season. (Hanley, 1990:790-1)

2.2 HYDRIC SOILS - ORGANIC AND INORGANIC.

Hydric soils are classified into mineral and organic soils, although the literature varies on the exact organic content of these soil types. Hammer defines organic soils as those containing greater than 12 to 20% organic matter and mineral soils as containing less than 12% organic matter. (Hammer, 1992:30) However, Mitsch states a mineral soil contains less than 20 to 35% organic matter. Furthermore, the USSCS (now the Natural Resource Conservation Service - NRCS) defines organic soils as:

> 1. saturated with water for long periods or are artificially drained and excluding live roots, (a) have 18 percent or more organic carbon if the mineral fraction is 60 percent or more clay, (b) have 12 percent or more organic carbon if the mineral fraction has no clay, or (c) have a proportional content of organic carbon between

12 and 18 percent if the clay content of the mineral fraction is between if the clay content of the mineral fraction is between zero and 60 percent; or

2. never saturated with water for more than a few days and have 20 percent or more organic carbon.

According to the USSCS's definition, any soil which does not fall under the criteria stated above is a mineral soil (Mitsch, 1993:116). Organic matter and percentage of organic carbon can be considered synonymous in these definitions. Furthermore, Hefner (1982) defines hydric soils as either (1) saturated at or near the surface with water that is virtually lacking of free oxygen for significant periods during the growing season, or (2) flooded frequently for long periods during the growing season.

Mineral and organic soils differ in several physiochemical features as summarized in the following Table 2-1 (from Mitsch, 1993 and Verry and Boelter,1979; with additions from Hammer, 1992:31):

Table 2-1 - Comparison of Mineral and Organic Soils in Wetlands

	Mineral Soil	Organic Soil
Organic Content, percent	< 20 to 35	> 20 to 35
Organic Carbon, percent	< 12 to 20	> 12 to 20
pH	Usually circumneutral	Acid
Redox Potential (eH)	-300 to +300 mv	-300 to +300 mV
Bulk Density	High	Low
Dry Weight	High	Low
Porosity	Low (45-55%)	High (80%)
Hydraulic Conductivity	High (except for clays)	Low to High
Water Holding Capacity	Low	High
Nutrient Availability	Generally high	Often low
Cation Exchange Capacity	Low, dominated by major cations	High, dominated by hydrogen ion
Dominate ions	Ca^{2+}, Mg^{2+}, Na^{+}	H^{+}
Typical Wetland	Riparian forest, some marshes	Northern peatland

(from Mitsch, 1993 and Verry and Boelter,1979; with additions from Hammer, 1992:31)

Organic matter in wetland soils generally varies between 15 and 75 percent (Faulkner and Richardson, 1989), with higher concentrations in bogs (90-100%)and fens (10-95%) (Mitsch and Gosselink, 1986) and lower amounts in open wetlands such as

riparian bottomland wetlands subject to mineral sedimentation or erosion. The abundance of organic matter in hydric soils occurs because decomposition of organic matter in waterlogged soils occurs at one-fourth the rate as occurs in aerobic soils. As a result, the organic matter builds up, and over hundreds of years an organic-rich soil is developed (Lyon, 1993). Organic matter has a very low reflectance of light and tends to make the soils very dark in color. This dark color is commonly an indicator of organic hydric soils, and the condition can be judged by low (/2,1/) chromas on the Munsell Color Charts (Lyon, 1993; Munsell Color, 1990). Generally, hydric soils are characterized by the presence of gray or black mottling, which results from the effects of anaerobic conditions on soil chemistry and the biochemistry of soil microorganisms.

Peat and muck are the most common types of organic hydric soils. The United States Department of Agriculture (USDA) Soil Survey Manual (USDA,1951; Shaw and Fredine, 1956) describes the formation of these soils:

> In moist situations where organic matter forms more rapidly than it decomposes, peat deposits are formed. These peats become, in turn, parent material for soils. If the organic remains are sufficiently fresh and intact to permit identification of plant forms, the material is regarded as peat. If, on the other hand, the peat has undergone sufficient decomposition to make recognition of the plant parts impossible, the decomposed material is called muck. Generally speaking, muck has a higher mineral or ash content than peat, because in the process of decomposition the ash that was in the vegetation accumulates.

Some experts have added a class of organic hydric soils, mucky peat (Hemists), making a total of three types (Verry and Boelter, 1979; Mitsch and Gosselink, 1993:119). In muck, two-thirds or more of the material is decomposed and less than one-third of the plant fibers are identifiable. If less than one-third of the material is decomposed and more

than two-thirds of the plant fibers are identifiable the soil is a peat (Fibrists). The third classification, mucky peat (Hemists) falls between peat and muck. Physical characteristics of fibric, hemic, and sapric peats from northern peatlands are summarized the table (Table 2-2) below (taken from Verry and Boelter, 1979):

Table 2-2 -- Range of Important Physical Characteristics of Fibric, Hemic, and Sapric Peats from Peatlands in Northern Lake States

Peatland Soil Type	Total Porosity (% volume)	Specific Yeild (% volume)	Hydraulic Conductivity (10-5 cm/sec)	Bulk Density (g/cm3)
Fibric	>90	>45	>150	<0.09
Hemic	84-90	10-45	1.2-150	0.09-0.20
Sapric	<84	<10	<1.2	>0.20

(taken from Verry and Boelter, 1979)

Organic soil, "peat", is formed when biomass production exceeds decomposition rate resulting in the accumulation of organic matter. The lack of oxygen (anaerobic conditions) in many wetlands slows the decay rates contributing to the presence of most organic soils in wetlands. Organic soil accumulation depends mainly on the production and decomposition of material in situ, rather than upon inputs of soil material from outside the wetland (Johnston, 1991).

2.3 OMBROTROPHIC to STRONGLY MINEROTROPHIC PEATLANDS.

There exists a continuum within peatlands based on pH, conductivity, ions. In ombrotrophic peatlands, nutrients and water primarily are brought into the system through rain, whereas in weakly, moderately, and strongly minerotrophic peatlands, nutrients and water enter the system primarily through the ground water and local surface run-off. The pH, conductivity, Ca^{2+} and Mg^{2+} ion values are at the low end of the continuum in ombrotrophic peatlands (bogs), and increase to the high end of the continuum in weakly, moderately, and strongly minerotrophic peatlands (fens). While there is no general consensus in the exact chemical ranges to be used, Andreas and Bryan (1990) proposed a delineation system which separates peatlands into five broad categories based on previous works by Heinselman (1970), Moore and Bellamy (1974), Larsen (1982), and Karlin and Bliss (1984). These categories are arbitrary subdivisions of a continuum which varies within microhabitats within any peatland (Table 2-3).

Table 2-3 - Classification of peatlands based on ranges in water chemistry characteristics. Taken from Andreas et al. (1990)

	pH	Conductivity umhos/cm	Ca^{2+} mg/l	Mg^{2+} mg/l
ombrotrophic (bogs)	3.2-3.8	20-27	0.6-2.1	0-0.2
semi-ombrotrophic	3.7-4.2	20-50	1.5-3.5	0.2-1.0
weakly minerotrophic	4.0-6.0	25-75	3.5-12	1.0-1.5
moderately minerotrophic	5.8-7.0	70-120	10.0-30	1.1-2.8
strongly minerotrophic (fens or rich fens)	7.0-8.0	>120	>30	>2.8

The differences in calcium (Ca^{+2}) levels are primarily due to the differences in calcium content of various water sources. Precipitation typically has a calcium content of 0.3-2.0 mg/L, surface and interflow, 2.0 to 10.0 mg/L, and groundwater, >10 mg/L with 30 mg/L or more common (Verry and Boelter, 1979). The higher level of calcium present in highly minerotrophic peatlands or fens is important because it reacts with carbonic acid from rain to form calcium bicarbonate, which dissociates in water to yield bicarbonate ions (Verry and Boelter, 1979). Fens and peatlands are often supplied primarily with groundwater which has passed through an aquifer rich in glacial till and acquired the higher level of dissolved calcium. Bicarbonate ions buffer most natural waters and yield pH values of 6 to 8 (well within the circumneutral 5-9 range). Peatlands with near neutral pH values, such as fens, contain more plant available nutrients and a greater diversity of plants and decomposer organisms than more acidic peatlands, including bogs (Verry and Boelter, 1979).

2.4 FENS AND BOGS.

2.4.1 Poor and Rich Fens. According to Stuckey (1981) and Shuey (1984), two types of fens occur in Ohio, bog fens or poor fens and prairie fens or rich fens. The two types of fens differ primarily in the plant species present. Subdividing fens into rich and poor was also suggested by Sjors (1961, 1963). Because fens superficially resemble bogs, many named fens in Ohio contain the term "bog" (Stuckey, 1981; Shuey, 1984:176-186).

A bog is a peatland supplied with water solely by precipitation or local surface runoff. Bogs often develop in glacial lakes or kettles, where peat accumulates as plant material gradually decomposes (Mitsch and Gooselink,1993). "Bog fens" contain many plants of northern distribution such as pitcher-plant (*Sarracenia purpurea* L.), tamarack (*Larix laricina* [DuRoi] K. Koch), and poison sumac (*Rhus vernix* L.) in addition to extensive stands of sedges and shrubby cinquefoil (*Potentilla fruticosa* L.), and often also contain lady slippers (*C. repedium* spp.). For the purpose of this experiment the term fen does not include these ombrotrophic "bog fens", but rather only the minerotrophic habitats Stuckey (1981) and Shuey (1984) refer to as "prairie fens". These "PRAIRIE FENS" are defined as containing a significant number of prairie species, most conspicuously big bluestems, in addition to containing extensive stands of sedges and shrubby cinquefoil (*Potentilla fruticosa* L.).

A fen is a peatland fed primarily by groundwater rather than exclusively by precipitation as is the case in a bog. Fens form where groundwater comes to the surface and the slow deterioration of organic matter results in a highly organic soil. When the water comes in contact with mineral soils and feeds the peatland with nutrients, it produces a broader range of vegetation than the mineral-poor soils found in true bogs.

2.4.2 Calcareous fens. In some fens, often called calcareous fens, artesian springs supply clear, cold, oxygen-deficient ground water that is moderately hard containing bicarbonates of calcium, magnesium, and rarely sulfates. Upon contact with the atmosphere at the earth's surface, these compounds are precipitated forming a grayish-white lime-rich substance, or marl. This marl, combined with an accumulation of organic

remains over time, becomes the primary substrate for the specific plants that colonize these habitats. The soils are sedge peat and circumneutral (5-9). Stuckey (1981) asserts the pH of substrate in the Ohio fens he studied was usually between 8 and 8.5. Horne and Goldman (1994) claim fen pH ranges from 5.1 to 7.6. However, other researchers claim fens have circumneutral (5-9) pH (Amon, 1993; Vitt, 1995; Mitsch and Gosselink, 1993). The literature on water chemistry parameters in fens has been compiled in Appendix A (Amon, 1993:5; Thompson, 1993; Charlton et al., 1988; Sims et al., 1982; Sjors, 1963; Vitt et al., 1975; Heinselman, 1970; Schwintzer, 1978; Slack et al., 1980; Glaser, 1983; Seischab, 1984; Nordqvist, 1965; Moore and Bellamy, 1974; Bares and Wali, 1979; Malmer and Sjors, 1955; Richardson et al., 1978; Gorham, 1956; Mitsch and Gosselink, 1986; Wood and Rubec, 1989; Riley, 1988; Wassen et al., 1990; Charlton, 1988; Damman and French, 1987; Walsh and Barry, 1958; Heilman, 1968).

2.4.3 Fen Meadows, Sedge Meadows, and Wet Prairies. The fen meadow plant community in some studies (Stottlemyer, 1989; Bliss, 1994) is characterized by three successional stages or zones of development, (1) open marl, (2) sedge-meadow, and (3) shrub-meadow. The open marl zone, an area as large as a few acres to as little as a few square feet, is characterized by shallow pools situated upon mucky well-exposed marl or by spring-fed streamlets traversing those zones that are successionally more mature. A sedge-meadow zone replaces the open marl zone as time progresses. The remains of sedges and other plants from the open zone begin to accumulate and a thin deposit of sedge peat is developed which subsequently covers the marl. As this sedge peat accumulates, it rapidly increases in thickness, often becomes slightly elevated, and the

terrain then becomes better drained. Later, at some distance from the artesian springs and the open marl zone, the amount of peat and mineral soils is substantially greater. Here the sedge-meadow zone is replaced by a shrub-meadow zone. Fen communities can make a transition to marsh, shrub-carr, and/or swamp forest if the highly calcareous artesian water supply is diminished or eliminated (Stuckey, 1981). Sedge meadows The soils are usually sedge peat or organic muck. These wetlands are open communities dominated by sedges (*Carex* spp.) with scattered horsetails (*Equisetum* spp.), blueflag, and cattails (Shuey, 1984).

Notably, it was not until the 1940's, however, that the word "fen", a colloquial term referring to plant communities of alkaline wetlands in Great Britain, was applied to this type of vegetation and habitat in the United States. Before this time, descriptions of fens were included as a part of discussions on wet prairies, alkaline bogs, peat bogs, marl meadows, or calcareous marshes (Stuckey, 1981:5).

In Ohio, prairie fens occur primarily in the west-central part in Champaign, Clark, Greene, Logan, and Miami counties, and bog fens in the northeastern portion in Holmes, Portage, Stark, and Summit counties. Elsewhere, they are more scattered (Stuckey, 1981:1). Fens and bogs (peatlands) have been documented to occur on or near glacial (calcareous in Ohio) substrates. Andreas (1985) found ninety-three (82%) of 114 Ohio peatlands (fens or bogs)investigated occurred on or near buried pre-glacial river valleys. Iftner (1992) and Bridgham and Richardson (1993) also found glacial till or ancient glacial lake sediments underlied bogs and fens.

2.5 PAST FAILURES, MIXED RESULTS, AND GENERAL NEED FOR ADDITIONAL RESEARCH.

Reviews of wetland restoration and creation projects published in the literature show highly mixed results. Some successes in wetland creations have been achieved and documented in the literature. Successes in the creation of salt marshes have been documented based on relatively long-term studies that find given the establishment of proper hydrology systems, created salt marshes appear similar to natural ones. (e.g., Seneca et al. 1976:186) Outcomes of USACE Dredged Material wetland projects have also been generally positive (e.g., Newling and Landin 1985). Despite these successes, failures abound in the literature.

Many wetland professionals are pessimistic about the ability to create wetlands equal to the natural wetlands they are being traded for under the current mitigation process. Although the U.S. Army and the EPA signed a memorandum of agreement in February 1990, clarifying the mitigation requirements of the Clean Water Act's section 404(b)(1) guidelines, and rhetorically shifting emphasis from "replacing" wetlands to "conserving" wetlands, it is not clear yet if this language shift has indeed resulted in a procedural or real shift in the permit process. Regardless, wetland mitigation and restoration projects can be expected to continue for some time into the future (Gardner,

1990:10337). It is clear from the mixed results of mitigation and restoration projects that there is still much to learn regarding wetland creation and mitigation.

Follow-up reviews of wetland creation found mitigation was often not even attempted. Bacchus (1991) and the Florida Department of Environmental Regulation (FDER) review of 119 wetland creation sites found mitigation was not attempted in 34% of the permits evaluated. In a report for the South Florida Water Management District (SFWMD) (Bacchus, 1991) found only 40% of the wetland creation projects required as mitigation from 1987 to 1991 had been attempted and only four of those attempted had met the stated goals listed in the permit. In Washington state Kuntz et al. (1988) found 5 of the 35 projects reviewed were never restored or negotiated. Kuntz et al. (1988) found mitigations in Washington resulted in a net wetland loss of 33% over 6 years (1980-1986).

Of those restoration and creation projects accomplished, many were failures or had mixed results. The FDER review (Bacchus, 1991) found a meager 27% success rate of the wetlands constructed were ecologically successful, and only 4 of the 63 permits were in compliance with the mitigation requirements. The SFWMD study also found undesirable plant species had invaded 80% of the projects (Bacchus, 1991).

Improper water levels and other flawed hydrologic designs are the leading causes of failed wetland creation projects. Bacchus (1991) stated 63% of the projects attempted in the SFWMD from 1987 to 1991 had hydrological problems. Race (1985) found numerous hydrological problems in the San Franscisco Bay projects from 1977 to 1982 including improper tidal elevations, channel erosion, and poor tidal circulation. Roberts (1993) reported Kentula's findings that the Oregon restoration and creation sites studied

had poor specifications for hydrology or vegetation. Furthermore, none of the Oregon projects examined was built as specified on the permit.

Several summaries of wetland restoration projects in California point to problems. Eliot (1985) evaluated permits of 58 projects in San Francisco Bay that required wetland restoration. She states that "...the 58 projects are diverse, frequently unsuccessful, and do not adhere to established mitigation policies. Many projects have not been completed. Of those that have been, many do not resemble the existing remnant marshes in San Francisco Bay."

Our ability to create or restore habitat for endangered species or other species is equally mixed. The restored wetland in the San Diego Bay, Sweetwater Marsh National Wildlife Refuge, failed to provide nesting habitat to the endangered light-footed clapper rail and the least tern as dictated by a federal court case ruling even nine years after the wetland's construction (Roberts, 1993). Kus (1994) studied the shorebird use of one created and six existing reference sites in a southern California estuary between March 1989 and September 1990. While species richness at the created site fell in the middle of the range for the natural sites, shorebird densities were significantly lower at the created site than at similar reference sites. This indicates that newly created wetlands can provide habitat for a large number of wetland-dependent bird species, but it may take considerable time before the created sites are capable of supporting populations of the size found in existing habitat.

Attempts to apply wetland restoration technology from the East Coast directly to the West Coast have met with limited success (Race, 1985; Zedler,1983). Differences in

environment, species composition, and types of disturbance preclude the application of techniques and specifications from the Atlantic and Gulf of Mexico coasts, or even from northern California, to southern California systems (Race,1985; Zedler, 1983).

In her review of past restoration projects conducted in the San Franscisco Bay over the period of 1977 to 1982, Race (1985) found that the widespread belief that marsh (wetland) establishment is a technologically sound undertaking has been based on a relatively small number of projects with only partial success, incomplete information, or anecdotal reports. As a result, actual acreages of marsh restored, covered with vegetation, at most large restoration projects have been only a fraction of each site's total area. Indeed, projects were often deemed "successful" or "completed" with very little vegetative coverage completed. The Salt Pond III project was described as a success in 1978, two years after construction, when only 10% of the 110 acre site covered by experimental plantings (Race, 1985).

Race (1985) stressed the need for continued research on man-made marshes and wetlands and recommends that carefully designed and documented experiments be included as part of restoration and mitigation projects whenever possible. She also stressed the need for long-term studies documenting the development of constructed wetlands beyond the very early successional stages. Kuntz (1988) and Josselyn and Buchholz (1984) found from their studies in Washington state and California respectively, that creation and restoration sites were not routinely monitored after project completion for compliance (Kuntz, 1988).

2.6 SPECIFIC NEED FOR FEN RESEARCH.

Millions of acres of wetland have been converted from one class to another through human activities (Dahl and Johnson,1991; Mitsch and Gosselink, 1993). Considering the period from the mid-1970s to the mid-1980s, a net gain of 220,200 acres of marshes occurred despite a loss of 563,900 acres to agriculture and other land uses because 790,800 acres of swamps and shrub wetlands changed to marshes by deforestation (Dahl and Johnson,1991; Mitsch and Gosselink, 1993). During this same time period, non-vegetated wetlands (ponds) increased by 792,400 acres: 78,700 acres converted from swamps, 49.1 converted from marshes, and 645,700 acres from agriculture and other land uses (Dahl and Johnson,1991; Mitsch and Gosselink, 1993). In 1993, Roberts, found the open water pond with a fringe of wetland vegetation (non-vegetated wetland), was the only wetland type that was increasing in acreage in the country. Kuntz (1988) found forested wetlands were not replicated at all in her review of mitigation projects in Washington State. In her 5-year Oregon study, Kentula (reported by Roberts, 1993) found twenty-three percent of the wetlands created in Oregon were open water ponds with a fringe of wetland vegetation (a weak marsh or non-vegetated wetland), though no natural ponds were impacted. This was attributed to the relative ease and cheapness of building ponds (Roberts, 1993). When interviewed by Breen (1993), Cooper, an authority on Rocky Mountain wetlands, expressed his concern that current federal regulations do not strictly require the created wetlands be the same type and thus function as those destroyed. It may be an equal trade in terms of acres, but is resulting in

a net-loss of wetland type and function. Many states, however, including Ohio, do require in-kind mitigation.

The majority of wetlands mitigation and restoration projects to date have attempted to create marsh and open water habitats. Practitioners have been fairly successful in creating freshwater marshes, where the hydrology is more apparent, but in bogs, fens, forested wetlands and other types of wetlands the water fluctuations, movement and hydrology is much subtler and harder to detect wetland creation has been less successful, less researched, and less often even attempted, and therefore our present capability to create other wetland types, particularly swamps, fens, and bogs, is more in question (Lowry, 1990:267). In her keynote address to the 11th Annual Conference on Wetlands Restoration and Creation, Hurchalla (1984), county commissioner of Marion County, Florida lamented that wet prairies (similar to fens) are viewed as less valuable than other wetland types and are probably the least studied and least understood of wetlands.

Fens are also thought to be difficult to create or completely replicate because of the long time required for fens to accumulate the peat deposits and evolve naturally. In an interview with Breen (1993), Carpenter of the Nature Conservancy pointed to the 8,000 years scientists estimate was required for the 714 acre High Creek Fen, "the most ecologically diverse, floristically rich" peatland in the Southern Rocky Mountains according to the Nature Conservancy, to evolve to its current state and build up its present peat deposits. Andropogon Associates (McCormick, 1991), a 17 year-old Philadelphia ecological planning and design firm, feel its not possible to re-create soil in a bog or other

wetland that took centuries to form but it is feasible to mimic certain vegetation or functions, including how soil stores and releases flood waters. Despite this Andropogon Associates have augmented sites with topsoil made from sludge and other organic waste in a landscape program in Rochester, New York which included wet meadows (fens).

The vertical accumulation rate of peat in bogs and fens is generally thought to be between 0.02 and 0.08 cm/yr in European bogs (Moore and Bellamy, 1974), while Nichols (1983) reported an accumulation rate of 0.15 to 0.20 cm/yr in warm, highly productive sites. Cameron (1970) gave a range of from 0.10 to 0.20 cm/yr for North American bogs. Johnston (1991) cited the annual thickness accumulation rate for organic soils in a sedge meadow in Cecil, WI, as 0.17 cm/year and 0.05 cm/year for a glacial *L. Agassis* peatland in Littlefork, MN, while Kadlec and Robbins (1984) stated 0.29 cm/year for a sedge meadow in Pentwater, MI, and . Johnston (1991) cited an average rate of thickness accumulation for mineral soil wetlands as 0.69 cm/year.

2.7 SOIL AUGMENTATION IN WETLAND RESTORATION PROJECTS - DISCUSSION

2.7.1 Dredged Material Substrate. Data on revegetation of dredged materials dates back to as early as 1878. Landin (1978) compiled a list of the 1120 plant species growing on 202 of the more than 2000 dredged material islands and sites built from 1878 to 1978. Information on the propagation of selected plant species was also noted. Extensive research has been conducted on wetland establishment using dredged material as a substrate by the U.S. Army Engineer Waterways Experiment Station (WES) and

others (Hunt, 1978; Garbisch, 1977; and Lindau and Hossner, 1981). The Dredged Material Research Program at WES began studying the establishment of freshwater and saltwater marshes on dredged materials in 1973.

<u>2.7.2 Soil Augmentation.</u> Augmenting the substrate of wetland projects with humic/organic soil from a donor wetland is done with the goal of making the soil more similar to that of natural wetlands. Many researchers recommend including native (hydric) soils in either inoculant quantities or cover quantities, because native soils contain dormant seeds, microorganisms, mycorrhizae, and macroinvertebrates and organic soils generally maintain saturated conditions which help wetland plants to survive droughts. (Munro,1991; USSCS,1992; EPA,1992; Cutlip,1984; Shuey, 1979; Helliwell,1989; Hollands, 1990). The EPA (1992) recommends augmentation with hydric soils as a means of quickly establishing the vegetation coverage and wetland functions.

Helliwell (1989) recommends soil transfer as a method of moving grassland and marshland vegetation. Lowry (1990) also recommends to transport the upper 6-12 inches of soil from the wetland area to be destroyed and re-deposit it as the surface layer for the created wetland. As a less time-consuming and expensive alternative to the movement of intact soil profiles, Helliwell (1989) recommends transferring the soil to the site by soil layers down to the depth of 1 m and placing them at the receiving site in a similar configuration.

<u>2.7.3 Mulching Or Soil Inoculation Methods.</u> Mulching or soil inoculation methods for establishing vegetation have many supporters. Weller (1981) stated that seed bank transplants were successful for many species, including sedges (*Carex* spp.),

Sagittaria sp, *Scirpus acutus*, *S. validus*, and *Typha* spp. The EPA/600/R-92/150 report recommends augmenting the soils of projects to make the organic matter content more like that of natural wetlands. Cutlip (1984), concluded wetland mulching or soil inoculation methods should be used as a seed source and spread over a larger area rather than used in an attempt to construct an organic soil. Shuey (1979) and Swanson (1980) found mulching resulted in a greater species diversity and a higher ground cover compared to either selective planting or natural recolonization of created Florida freshwater marshes.

2.7.4 Unpredictability, Mixed Results and Drawbacks of Soil Augmentation Methods. Although Garbisch (1977) found no reported cases in which uncontaminated dredge sediment types failed to function well as substrate for marsh establishment, he is not a proponent of transplanting soil from a donor wetland (topsoiling) as the sole process for vegetation establishment. Garbisch's review of the literature and discussions with fellow practitioners did not reveal any successful wetland development projects that used the process of topsoiling to introduce vegetation. Topsoiling is a complex process that produces variable results because of the issues of seed bank viability and species composition, amount and timing of soil removal, and manner and effects of the mechanical manipulations of the soil. Garbisch, who had undertaken 250 restoration and creation projects as of 1988 (Kusler,1988), views topsoiling as highly experimental and recommends it be pursued with caution.

Maltby (1987) stated that re-creating the organic soil profile exactly in a wetland system is difficult, and can be regarded as impossible for all practical purposes. Reuse of

organic soils from the lost wetland area is preferred, but also presents problems of excavation (often requiring low load-bearing tracked equipment, stockpiling, soil chemistry changes, organic matter decomposition, sediment control, stabilization of these soils, and water quality protection (Maltby, 1987; and Hollands, 1990).

Research on different techniques for the establishment of wetland vegetation conducted in Massachusetts found that while the use of transferred soils resulted in rapid development of wetland vegetative coverage, it did not guarantee identical species composition. In addition, undesirable plants contained in the soils, such as purple loosestrife, may create management problems which may become limiting factors in achieving mitigation goals (Hollands, 1990).

The results of topsoiling are unpredictable. Jarman (1991) found although the use of soils taken from the wetland permitted for destruction as substrate in the creation of forested red maple wetland sites resulted in rapid development (75% cover within 2 growing seasons) of vegetative coverage, it did not guarantee species composition identical to the original natural wetland. Almost half of the species observed in the five created sites were not present in the lost wetlands (Jarman, 1991). The USSCS Engineering Field Handbook on Wetland Restoration, Enhancement, or Creation(1992) and Amon(1995), contend buried wetland seeds may remain viable for 70 to 80 years in wet soils. Environmental factors, such as harsher exposure to light and weather, impact the germination of seeds in the restorations areas, resulting in a different species composition. In addition, donor seed banks will not produce vegetation identical to the local native vegetation from which they were taken because some native species may not

be present in the seed banks or their seeds may lose viability rapidly when topsoil is stockpiled. Nevertheless, donor soils can be used to establish rapidly a species-rich vegetation dominated by native species that are adapted to local conditions (van der Valk, 1989). Relict (old) seed banks can play a role in the restoration of native vegetation, but their utility diminishes with time because seeds of desirable species lose their viability and those of undesirable species accumulate.

2.8 SOIL TYPE AND WATER CHEMISTRY IMPACT ON VEGETATION SUCCESS.

2.8.1 Soil Organic Matter Content, Soil Texture, and "Hardness" vs Vegetation Establishment. The percent soil organic matter determines the suitability as a planting and growth medium, according to the EPA document, Classification of Wetlands and Deepwater Habitats of the United States, (EPA/600/R-92/150, 1992). The proper percentage of organic matter and the proper soil texture and "hardness" are required to allow penetration by roots and rhizomes for vegetation establishment. Soil organic matter also provides necessary nutrients for microbial growth. The organic soils also have a higher capacity for water retention and an increased proportion of this water is available for plant growth.

2.8.2 Effect of Soil Type on Vegetation Growth. Soil type and chemistry are important factors in determining the success of a natural or constructed wetland. Limited

research exists on the productivity and prosperity of individual species in specific types of wetlands with regards to hydric and non-hydric soils. Williams (1992)studied the effects of hydric and non-hydric soil on the first-year performance of oak species in bottomland hardwood wetlands on the Mississippi Alluvial Plain. He found the Nuttall and Water oak species survived equally well in non-hydric and hydric soils, while the Cherrybark oak actually survived better (90%) on the non-hydric soil compared to 50% survival on the two types of hydric soils tested (Williams, 1992).

2.8.3 Fen Soil Chemistry Effects On Vegetation Growth. The role of soil chemistry, and nutrient availability in the success of marshes has been studied but little research has been published to date with regard to fens (Neill, 1989). Researchers (Snowden and Wheeler, 1993; Wheeler, Al-Farraj, and Cook, 1985; and Shaw and Wheeler, 1991) have proposed and/or observed correlations between the iron tolerance of fen plant species and their field distribution and species richness. The application of nitrogen and phosphorous fertilizers has been found to increase biomass production in prairie (lacustrine) marshes (Neill, 1989).

2.9 SUCCESSION WITH RESPECT TO FENS

2.9.1 Succession - Glacier Bay National Park Case. Stottlemyer (1989) studied ecosystem succession in Glacier Bay National Park and Preserve, examining a spectrum of five watersheds in differing stages (40-350 years following deglaciation)of primary and secondary succession following deglaciation. It is proposed that the succession of gravelly/mineral soil in our fen might be similar to the succession of glaciated soil encountered in Glacier Bay. The research set out to (1) determine chemical change which occurs following deglaciation, (2) relate soil acidification to presence of organic mater, soil NO_3, and total N, and (3) estimate the downward movement of ionic species within the soil profiles with increasing acidification from advancing plant succession.

Nitrate levels were found to be high in the discharge streamflow from early successional ecosystems. *Alnus sinuata*, a major nitrogen fixer, dominated the vegetation in these early successional ecosystems. This could help show that "nitrogen fixers" might thrive or prosper better than other vegetation on the gravel than in hydric soil (Quayle, 1996). Stream discharge of NO_3^- suggested that early successional ecosystem N fixation exceeded biotic uptake. This was confirmed by examining NO_3^- soil extractions and lysimeters. Concurrent with increased NO_3^- concentrations below the rooting zone was increased H^+ which increased 100 times during 25 years of primary succession. This natural acidification from a mobile NO_3^- ion resulted in an pronounced increase in soil base cation leaching and mobilization of aluminum in the soil profile. The magnitude and

short time required for such acidification greatly exceeded anything projected or modeled for systems impacted by anthropogenic inputs. This data suggests that most early successional ecosystems at Glacier Bay would be sensitive to anthropogenic inputs of NO_3^-(Stottlemyer, 1989). Extending this to fens, it could be theorized mineral soil (glacial till) used to construct a new fen would eventually build up additional nitrogen content and become similar to levels found in hydric wetland soil.

A study of primary and secondary ecosystem succession in Glacier Bay National Park and Preserve, showed progression from recently deglaciated rocky areas or "soils" to eventually *Carex*-dominated wet meadows (fens) (Bliss, 1994). This pattern of succession gives some credence to the proposition that gravelly soils may be able to support fen vegetation as well as the organic/humic soils. It might be possible for wetland plants to prosper in inorganic soil if they could obtain their nutrients from the air or the water source instead. For example, *Alnus sinuata*, a major nitrogen fixer, dominated the vegetation in the early successional Glacier Bay ecosystems (Bliss, 1994). This begs the question of whether another nitrogen fixer, *Epilobium* sp, might fare well in a mineral glacial till soil. In addition, the role of soil chemistry, and nutrient availability in the success of marshes has been studied but no research has been published to date with regard to fens (Neill, 1989).

2.9.2 Succession - Canadian High Arctic Case. Bliss (1994) studied the succession in Canadian high arctic habitats by examining the topographical vegetation patterns and soil data. He developed a theory on the chronological sequence of succession in these areas progressed from bare rock (shattered dolomite) shoreline to

Carex- dominated wet meadows (fens). The authors concluded that the chronological or successional sequence was from marine algae deposited on shore --> to *Puccinellia* (grass) sp-dominated --> to *Dupontia* (grass) sp-dominated --> to *Carex*-dominated meadows. Reduced levels of salinity and of nitrogen fixation upslope (from the shore) along with increased depth of organic soils and ability of soils to hold more soil water appear important in this succession (Bliss, 1994). *Carex* sp have been documented to be able to tolerate nutrient-poor habitats in Alaska (Bliss, 1994).

However, the researchers found that the inland *Carex* meadows, fens, in the Canadian high arctic contained lower levels of nutrients than the coastal *Carex* meadows. This was attributed to long-term leaching of nutrients with the massive spring runoffs. In the inland fens do not follow the same successional pattern as occurs along the coast where facilitation in building a peaty soil that holds considerable water is important in the initial establishment of the sedge meadows (Bliss, 1994).

In many world ecosystems, the pioneer successional stages provide the major input of nitrogen (Gorham et al. 1979). In the high arctic coastal areas studied, the *Carex* meadows still fixed considerable amounts of nitrogen even though they represented the later successional stages.

2.9.3 Succession - Development Of Hydric Soils Over Time. If hydric soils are not already present, management of water levels and water chemistry may be necessary to encourage their development (EPA, 1992). Hydric soil conditions begin to develop as soon as the ground is saturated (flooded) and anaerobic conditions are present.

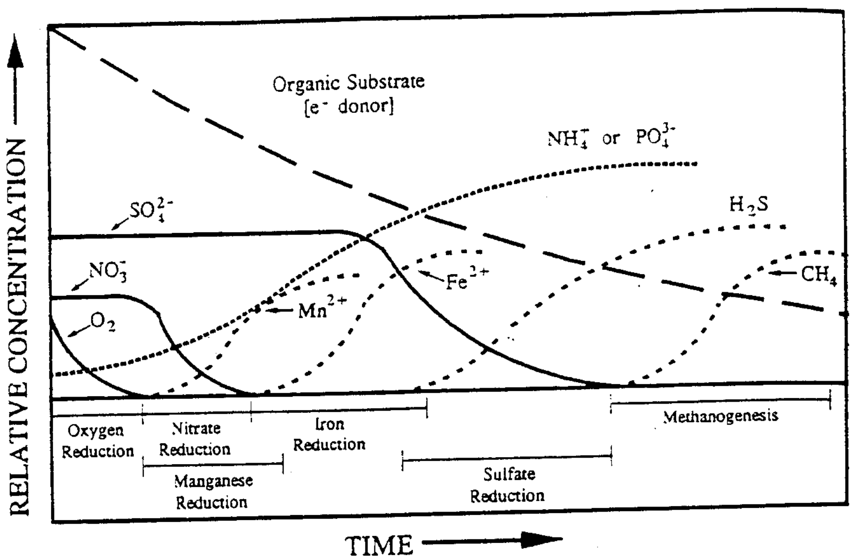


Figure 2-1 - Relative chemical Concentration vs Time After Flooding -- Succession/Development of Hydric Soil Conditions

Several studies show that nitrogen, phosphorous, and organic matter increase with the age of the created site (Reimold et al, 1978; Lindau and Hossner, 1981; and Craft et al., 1988). Cammen (1974) estimated the lower organic carbon content found in created marshes in North Carolina would reach reference levels in 4 to 26 years. Lindau and Hossner (1981) found after 2 years, organic matter concentrations, total nitrogen, and ammonium-nitrogen levels in experimental marsh soils from Texas dredged spoil projects were still on average 2-3 times lower than those in natural marshes. Lindau and Hossner

(1981) proposed that given a linear rate of increase, concentrations of these parameters would be equal to those in surrounding marshes in 2 to 5 years.

Other researchers are not as optimistic in their predictions. Race and Christie (1982) claimed that "no man-made marsh to date has shown the stabilization of physical and chemical properties in the range of values for natural marshes." Likewise, Craft et al. (1988) concluded from a comparison of natural and planted soil in 5 sites, that organic matter pools develop in 15 to 30 years but development of soil carbon, nitrogen, and phosphorous pools take much longer.

2.9.4 Succession - In Restored And Created Wetlands In General. Race (1985) also raises the question of time constraints with regard to wetland development over the short-term and long-term. Permits rarely address the issue of how long it should take for the habitat to develop to the desired extent. Alternatively, some permits have required the maintenance of marshes in their current state, ignoring the fact that even natural marshes are dynamic, successional habitats (Race, 1985). The 1990 "Wetland Creation and Restoration - the Status of the Science," recommends that regulators set standards for long term monitoring that demand "persistence" not "constancy" for restored and created wetlands (Willard and Hiller, 1990).

2.10 WETLAND MITIGATION COSTS.

Wetlands mitigation can be a costly endeavor with highly unpredictable and often unsuccessful results. One study of the costs associated with nearly 1000 wetland creation and restoration projects found the average cost per acre, not including purchase cost of the land, ranged from \$1,000/acre to \$779,000/acre; while the overall maximum cost was \$2,588,000/acre (King and Bohlen, 1994). The table (2-4) on the next page gives a more detailed look at their findings.

Table 2-4 --- Wetland Restoration and Creation Project Cost Estimates and Cost Allocation by Task and by Input Category

	Project Type								
	Aquatic Bed	Complex FW	Mixed	FW Forest	FW Emergent	Tidal FW	Salt Marsh	Mangrove	Agricultural Conversion
Project Costs (Thousands)/acre									
Average	$9.5	$56.7	$25.3	$77.9	$48.7	$42.0	$18.1	$18.0	$1.0
Minimum	18.3	4.3	1.4	0.9	1.7	0.6	1.0	2.1	0.005
Maximum	21.7	258.8	65.8	248.4	170.6	92.6	43.6	42.8	20.8
Median `	18.6	24.8	23.4	42.7	35.2	32.9	10.2	13.6	0.5
Sample Size	3	8	10	19	28	3	9	4	494
Breakdown by Tasks:									
Before Construction	17%	10%	5%	9%	13%	9%	16%	13%	0%
Construction	63	74	78	74	58	87	73	66	100
After Construction	20	16	17	18	28	4	11	21	0
Breakdown by Input Category:									
Labor	58%	50%	74%	51%	63%	31%	52%	51%	45%
Materials	8	23	10	30	26	54	27	21	0
Equipment	34	14	16	18	9	14	20	28	55
Other	0	14	0	2	1	1	2	0	0

(King and Bohlen,1994)

* Cost data for agricultural conversions are drawn from the secondary data. Cost breakdowns for agricultural conversions are based on a project consisting of hydrologic modification without planting or formal plan development.

FW=Freshwater

Similarly, Mitsch and Cronk (1992) compiled a table of construction costs of wetlands from the literature:

Table 2-5 - Wetland Construction Costs (from Mitsch and Cronk, 1992)

Wetland	State	Use	Area (ha)	Cost $/hectare	Cost $/acre
Ballona Wetland	CA	habitat, recreation	87.4	$70,100	$28,400
Greenwood Urban Wetland	FL	stormwater runoff	11.0	$51,500	$20,800
Lake Jackson Restoration	FL	urban runoff	4.0	$199,500	$80,700
Santee Marsh	CA	wastewater treatment	0.1	$1,820,000	$737,000*
Iselin Marsh/Pond/Meadow	PA	wastewater treatment	0.2	$2,080,000	$842,000*
Pintail Lake	AZ	wastewater treatment	20.2	$73,800	$30,000
Jacques Marsh	AZ	wastewater treatment	18.0	$75,300	$30,500
Kash Creek (Impoundment 3)	AL	acid mine drainage	0.4	$84,200	$34,000
SIMCO Mine	OH	acid mine drainage	0.2	$480,000	$194,000
Widows Creek Steam Plant	AL	ash pond seepage	0.5	$69,800	$28,200
Kingston	AL	ash pond seepage	0.9	$142,100	$57,500
Bolivar Peninsula	TX	disposal site for dredge	8.0	$34,100	$13,800
Windmill Point	VA	disposal site for dredge	8.0	$25,300	$10,300
Blue River Reclamation Project	CO	riparian restoration	12.0	$41,300	$16,700
			AVERAGE	$374,800	$152,000
			MEDIAN	$74,500	$30,200

includes area on which an impoundment and filter were built
*cost reflects entirely artificial wetland and includes a good deal of plumbing

3.0 Methodology

3.1 SITE

3.1.1 Site selection. The topography, vegetation, soils, source of deep groundwater, and relation to surrounding ecosystem were evaluated in determining the research site. The presence of soils suggesting prior wetland characteristics, a plant community that included some wetland species, and its proximity to an existing, ground water-supplied wetland supported the belief the site was once part of the nearby Beaver Creek wetland system.

The presence of a deep source of groundwater under pressure was a key selection factor. The waterflow from this source would be deep enough so as not to be influenced directly by rainwater, thus providing a steady waterflow source. The water from this source is flowing through a gravel layer and thus has consistently high conductivity, high levels of Ca^{2+} and Mg^{2+}, and has a year round temperature of 10.9 °C, further mimicking the characteristics of fen water sources (springs and seeps). The close proximity of the natural wetlands helps ensure ecological interactions, precipitation and temperature patterns, consistent with the natural system. The local wetlands also serve as a seed source and provide indigenous wetland animals to interact with the site.

3.1.2 Site Geology. The research site is located in Greene County, Ohio (Figure 3-1). It is immediately adjacent to the natural wetland environment bordering Beaver Creek, in the Beavercreek township, and is owned by the Ohio Department of Natural

Resources, Division of Wildlife. A small creek borders the site on the North, while a grass meadow bounds it on the South. To the West is the natural wetland, and on the East is an agricultural field used to grow corn and soybeans (Figure 3-2).

The research site chosen was a previously farmed area located on the eastern edge of a broad, north-south directed depression framed by gravel-rich glacial till ridges to the East and West (Amon, 1993). Underlying the research site are unconsolidated glacial deposits 30-35m over limestone and shale bedrock. The bedrock consists of Upper Ordovician shales and shaley limestones belonging to the Richmond, Maysville, and Eden Groups (Norris, Cross, and Goldthwait, 1950; Hite, 1994). These bedrock formations are characterized by low primary porosities and permeabilities (Strecker, 1993; Hite, 1994).

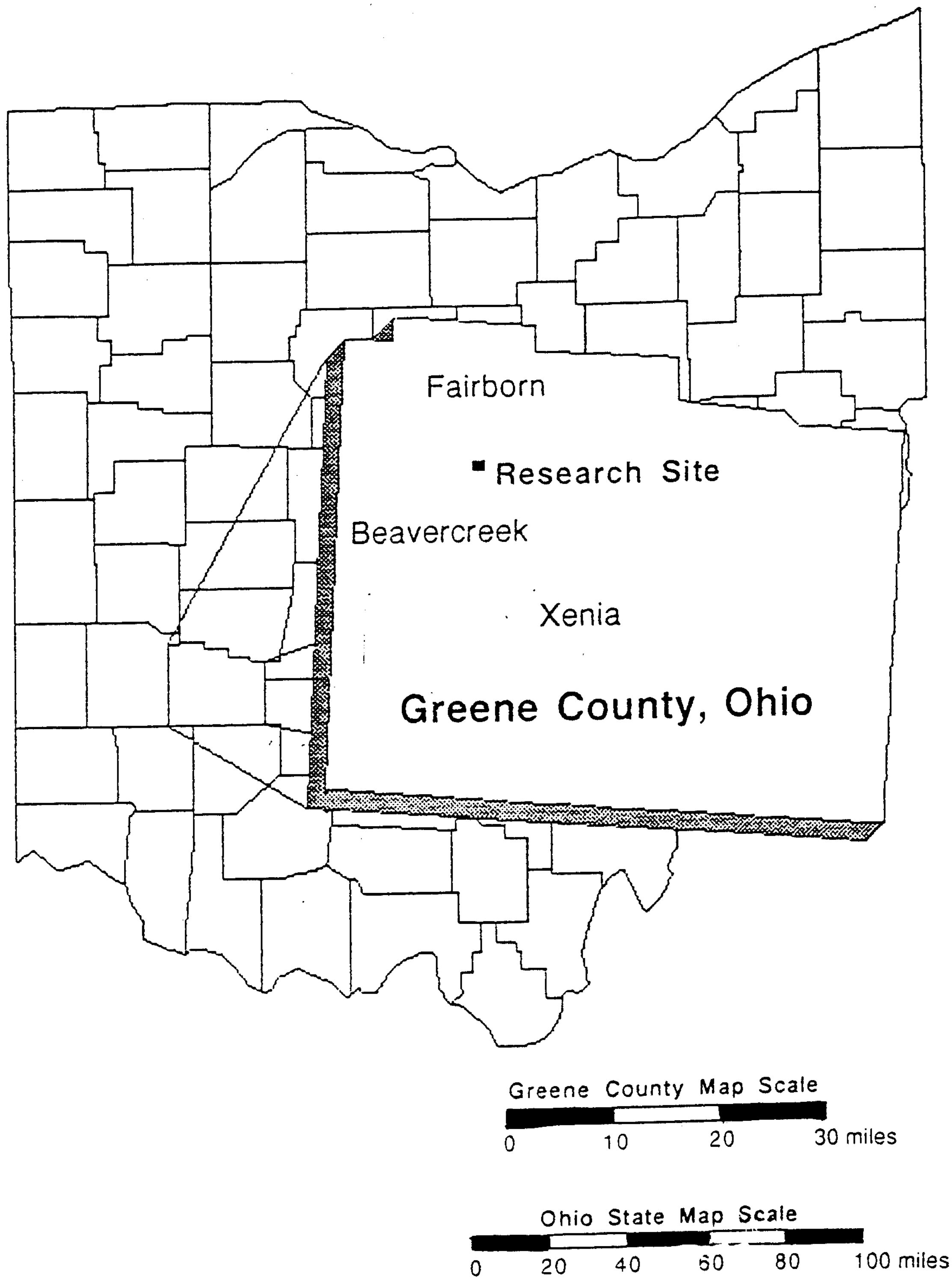


Figure 3-1 Location of Experimental Fen Site within Ohio

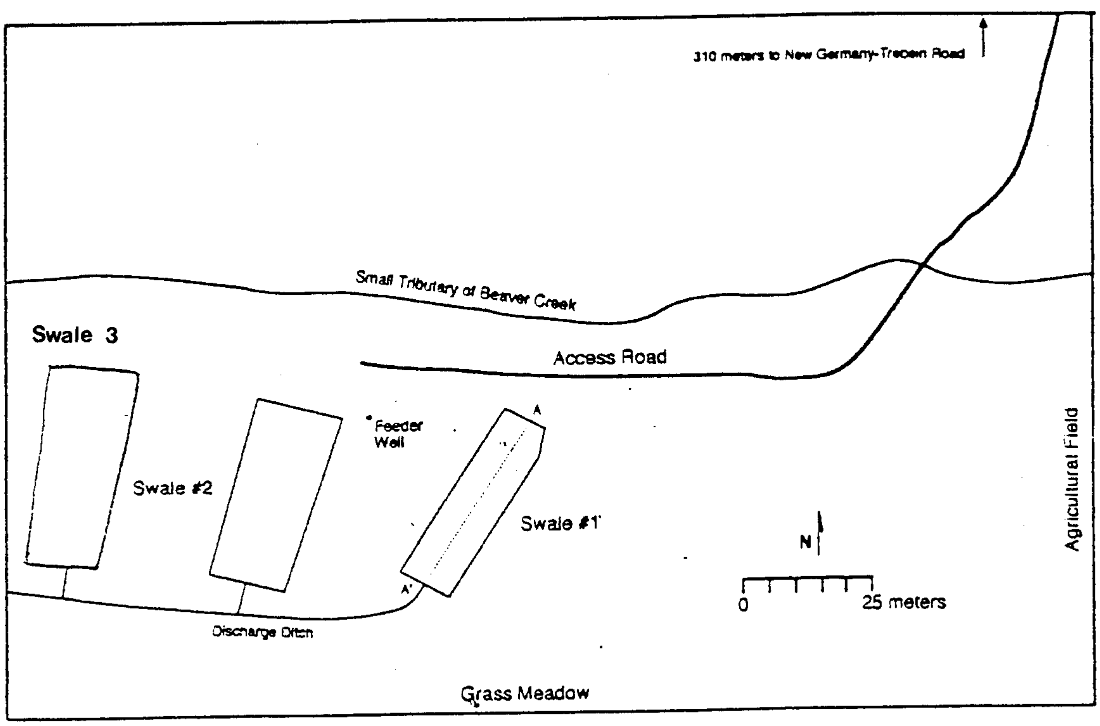


Figure 3-2 Close-up of Research Site Location (Swale #3)

Overburden at the research site is extremely variable, with layers of sand and gravel interspersed by discontinuous clay and silt lenses (Whitteberry, 1992; Hite, 1994). The unconsolidated overburden consists of valley train deposits of sand and gravel from the Scioto Lobe of the Wisconsin glaciation (Wilding, et al., 1971). A 1.2 m topsoil layer of Westland silty clay loam (Garner, et al., 1978) overlies a banded, cohesive clay unit (Hite, 1994).

3.1.3 Site Hydrology. The research site is located within the Beaver Creek drainage basin (Haynos, 1991). Beaver Creek is a tributary of the Little Miami River, located 4-5 miles south of the research site. The original site surface was 2 to 4 ft above that of the nearby Beaver Creek wetland. A deep confined groundwater layer occurs at roughly 70 ft (~21.3 m) depth and has a head of pressure more than 18 in (45.7 cm) above the constructed fen surface. In addition to this piped-in deep groundwater source, near surface water will also seep into the fen site. The near surface water table at the research site is located at 0.6 to 1.2 m (0.4 to 3 ft) beneath the original farm land surface (Amon, 1993). Hydrologic observations from 1988 through 1991 indicated that ground water is near the surface in the lowest portions of the site and is flowing to the West, toward Beaver Creek (Whitteberry, 1992). However, flow patterns within the extreme shallow subsurface, less than 1.2 m beneath the ground surface, are more likely to be governed by seasonal variations in water levels and spatial distribution of porosity and permeability.

3.1.4 Site Construction. During construction the topsoil was removed to a depth of roughly 3 ft (91.4 cm) where clay was encountered. The organic soil was mixed with some of the less organic overburden and stockpiled for later use to one side of the site.

Unsorted gravel till was hauled to the site from a glacial deposit about 500m South of the constructed fen. A gravel till layer of approximately 6" (15.24 cm) was laid down across the entire site. An additional 6" (15.24 cm) of gravel till was placed on top of that on the gravel side (west) of the site. Then 6" of the previously removed and stockpiled hydric topsoil was placed on top of the 6" (15.24 cm) gravel base on the soil side (east) of the site (Figure 3-3). The surplus hydric soil was spread over a nearby field and reseeded with winter wheat and a prairie seed mixture. Heavy equipment including a tracked hoe and bulldozer were used in this portion of the construction. The site needed to be roughly level with only a slight downward gradient (18 cm (~7") over 32m) from the well (north) end to the exit ditches at the south end of the site. Because the saturated state of the site prohibited the use of heavy equipment to do this fine grading work, final leveling was accomplished manually with shovels and buckets. Surveying equipment was used to check the final grade. The exit ditches at the downhill end of the site were hand dug, and the ditch leading from the site to the Beavercreek wetlands was cleared of overgrowth. Weirs were also installed in the two exit ditches to facilitate obtaining flow rates and clean water samples from these locations.

A 70-ft-deep (~21.3 m) artesian well was established and water was piped from the well to the site bed through two-inch polyvinylchloride (PVC) pipe to the gravel and soil sides of the site respectively (Amon, 1993). The ratio of water flow to the two sides is controlled by separate valves at the well head. Perforated two inch PVC pipe (well screen) then runs the length of both the gravel and the soil sides ending near the exit ditches. This perforated pipe was then covered by a layer of reinforced polymeric felt

(geotextile) fabric to protect the pipe from damage and siltation. In addition, a boardwalk of 2"x10" untreated pine lumber (Figure 3-4) runs above ground directly over the pipe location on both sides as additional protection of the pipe from breakage. The perforated pipes were installed nearly level to ensure even water flow all along the length of the site.

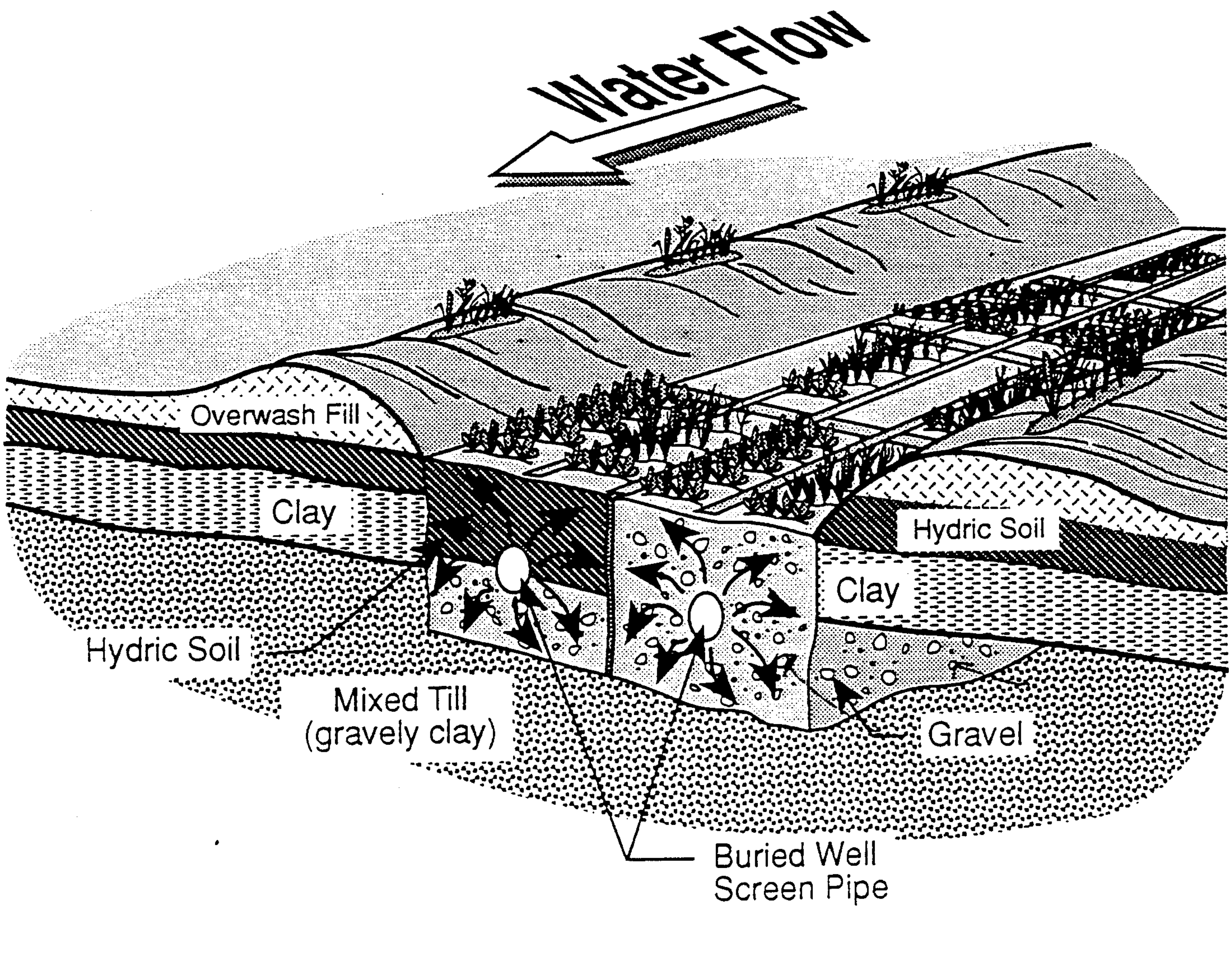
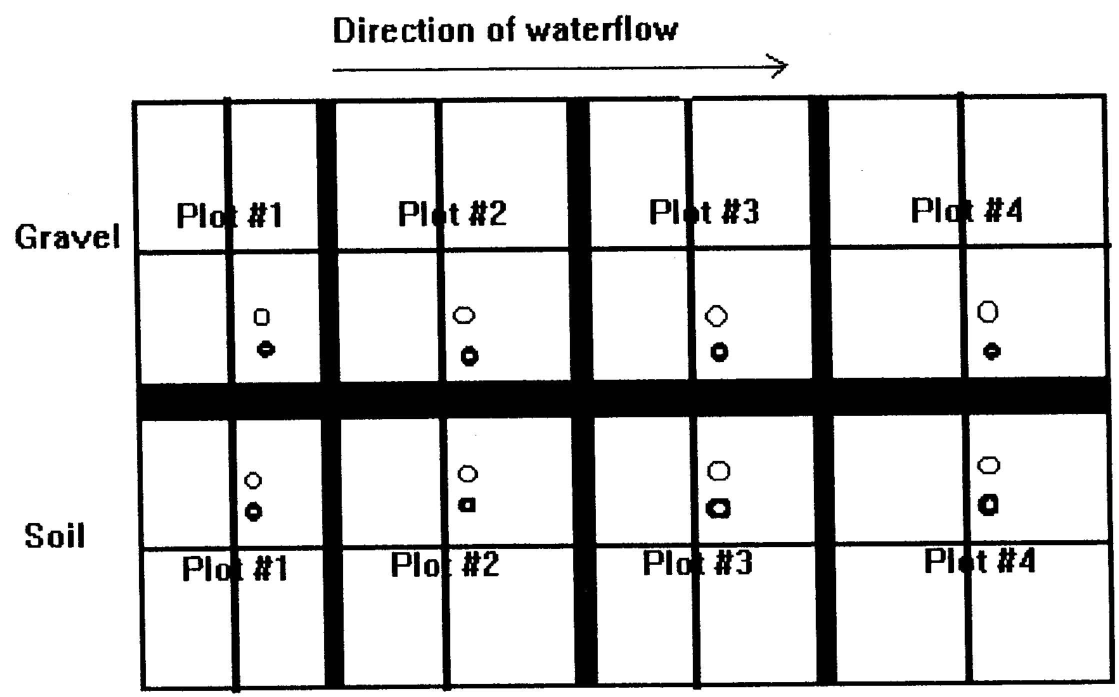


Figure 3-3 End-view of Wetland Research Site

A grid of 2" x 10" x 8' untreated white pine boards was laid out (See Fig 3-4). The boardwalk protects the perforated water supply lines. The boardwalk also divides the planting areas, and to provides researchers walking access to the site without their sinking into the saturated ground, changing the topography of the site and thus altering the growing conditions for the plants. Boards 2"x10" x 8' were used because narrower or shorter boards would not adequately distribute the weight of one or two individuals.

3.1.5 Site Layout. The wetland site is 15.5 m wide and 32.0 m long. It is divided lengthwise into two substrate types: unsorted gravel till and hydric organic soil. Each soil type control area is further subdivided into four duplicate areas. Figure 3-4 shows an overview of the site layout, while Figure 3-5 shows an enlarged view of one of these duplicate areas. Each of these areas contains six distinct subareas. An area 4.0 meters by 3.75 meters contains a grid of greenhouse grown plugs. A second area, also 4.0 m by 3.75 meters contains a grid in which 33 species of plants were planted from seed on 21 Apr 95. A third area 2.0 meters by 3.75 meters contains a grid of 20 different plugs dug and transplanted (within 2 hours) from natural wetlands representing different plant mixtures and different wetland sources. The greenhouse plugs were planted 22 Apr 95 in both the soil and the gravel substrates. A fourth area measuring 2.0 meters by 3.75 meters contains a seed mixture of over 25 different species (planted in an area of only 2.5' x 7.0'). A fifth area 2 meters by 3.75 meters was planted with *Epilobium coloratum* seed. The sixth area measuring 2 meters by 3.75 meters was used to see what would come up from the seed bank or from seed transported in naturally. Additional plant species were also placed in this sixth area which were not studied under this research effort.



○ Well sampling from upper 0"-6" below the surface [in the root zone]

O Well sampling from lower 6"-12" below the surface [below the root zone]

Figure 3-4 - Overview of Site Layout

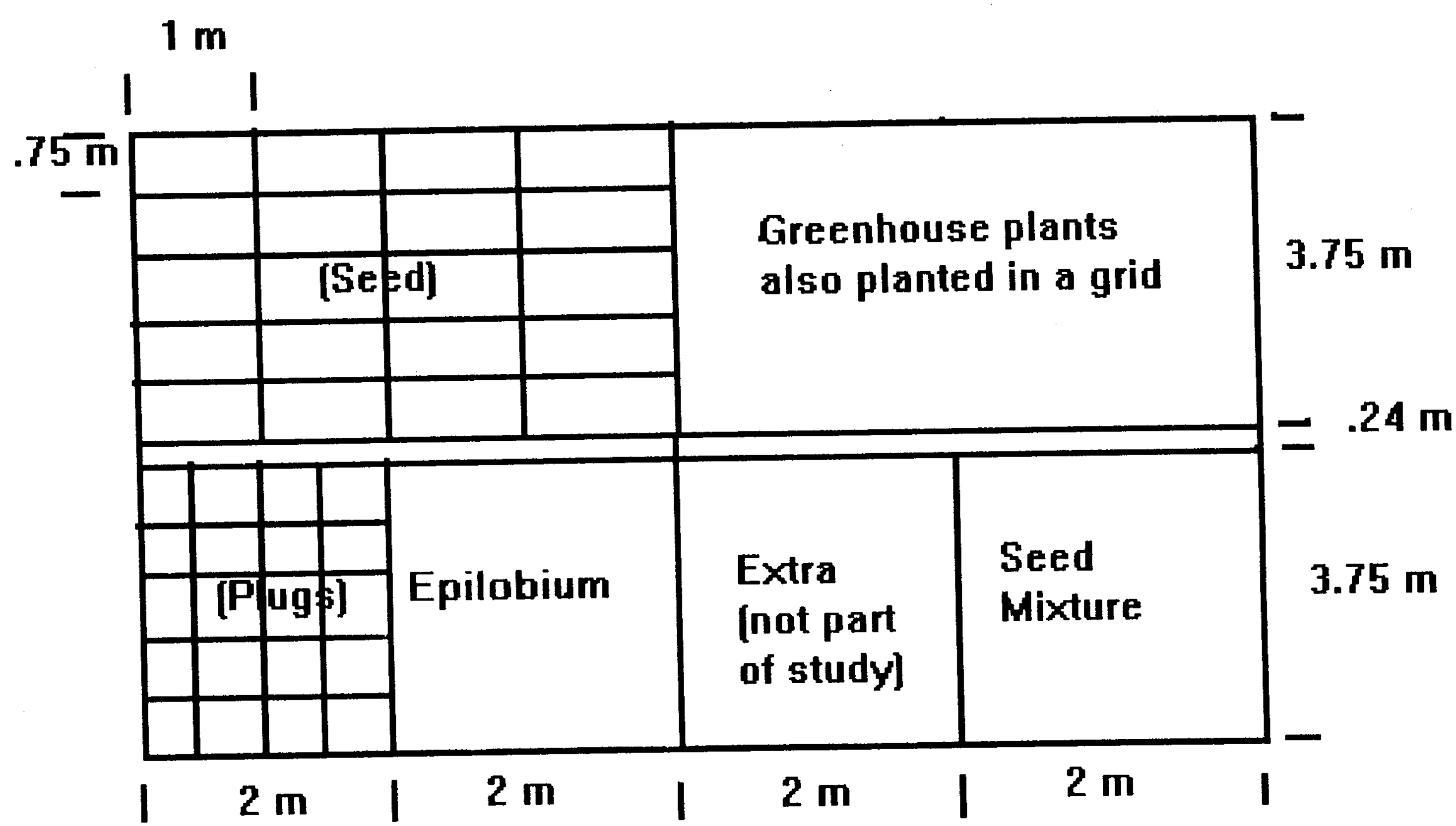


Figure 3-5 -- Enlarged View of One Plot (Planting Replicate)

3.1.6 Seed Preparation. Seed stock used for the greenhouse grown plants and the seeded areas was gathered from local wetlands within a 10 mile radius of the research site. Seed was cleaned and placed in moist sand (for till planting) or hydric soil from the restoration site (for soil planting) and held 8-18 weeks at 1 °C prior to planting. Plugs were also transplanted from local natural wetlands. Each plug as approximately 4" x 4" and was placed in the substrate without removal of soil. The sites chosen for collection of plugs represented a broad spectrum of habitat types within the Beaver Creek Wetlands.

3.2 DATA COLLECTION AND ANALYSES

3.2.1 Plant Height. Maximum plant heights, presence or absence of species were noted, biomass samples, and water samples were gathered from the site. The height of the tallest plant of each species planted was measured at roughly weekly intervals. Individual plants were not measured individually because there were too many. The time requirements would have been prohibitive, but more importantly excessive walking on the site and handling of the plants could damage the plants and alter the results of the experiment. The maximum plant height was used rather than the median plant height because it was thought there would be excessive error incurred in the application of visually judging the median plant height, whereas the maximum plant height was a more objective measurement. The plant heights were measured using a 3 foot long measuring stick with divisions of one tenth of a foot marked on it. The stick was held vertical next to the tallest specimen (roughly perpendicular to the ground surface) and the plant height read off the stick and recorded on data sheets (Figure 3-6).

Date:	Soil Type: Gravel Soil	Plot #: 1 2 3 4	Origin: Seed Grnhs	Name:
(24) *Mentha* sp 3 (Mint 3)	**(26)** Sanguisorba canadensis (Canada Burnet)	**(28)** *Scirpus pendula* (Drooping Bulrush)	**(30)** *Scirpus Validus* (Soft-ste	**(32)** *Angelica atropurpurea* (Great Angelica)
(25) *Carex Cristatella* (Crested Sedge)	**(27)** Phytosegia purpurea (Purple Dragon-head)	**(29)** *Thelypteris thelypteroides* (Marsh fern)	**(31)** *Verbena hastada* (Blue Vervain)	**(33)** *Solidago riddelii* (Riddell's Goldenrod)
(17) *Gentiana Clausa* (Closed Gentain)	**(19)** *Juncus articulatus* (Jointed Rush)	**(20)** *Juncus torreyii* (Torrey's Rush)	**(21)** *Lobelia Cardinalis* (Cardinal Flower)	**(22)** *Mentha* sp 2 (Mint 2)
(18) *Asclepias incarnata* (swamp milkweed)				**(23)** *Carex prairea* (Prairie Sedge)
(9) Carex vulpinoidea (Fox sedge)	**(10)** *Chelone glabra* (turtlehead)	**(12)** *Eupatoriadelphus maculatus* (Joe Pye)	**(13)** *Eupatorium perfoliatum* (Boneset)	**(15)** Filipendula rubra (Queen of the Prairie)
	(11) *Potentilla fruticosa* (Shrubby Cinquefoil)		**(14)** *Carex Frankii* (Frank's Sedge)	**(16)** *Pycnanthemum* (Mountain Mint)
(1) *Carex hystricina* (Porcupine Sedge)	**(4)** *Carex stricta* (tussock sedge)	**(5)** *Carex lurida* (Shallow Sedge)	**(7)** *Carex lupuliformis* (False Hop Sedge)	**(8)** *Carex stipata*
(2) *Mentha* sp (Mint) **(3)** *Pedicularis lanceolata* (Swamp Loosewort)		**(6)** *Cacalia sauveolens* (Sweet-scented Indian Plantain)		

Figure 3-6 -- Plant Height Data Recording Sheet -- Planting Layout for Areas Planted From Seed or Greenhouse Stock (33 species in a 5 x 4 grid)

3.2.2 Biomass from Seed Mixture Areas.

3.2.2.1 Biomass Sampling. A random sampling plan was used for sampling biomass from the seed mixture areas. Biomass samples were not taken of the individual species from the individual seed and greenhouse plug areas because the sample size would be so large, relative to the size of each area, that it would be too destructive to the research site's growth in the following year(s). The seed mixture was also thought to be representative of the success in the soil types. The seed mixture areas were 2 1/2' x 7' (~76 cm x 2.13 m) as a minimum. Three replicate samples of roughly 6" x 6" or 15 cm x 15 cm in each mixture area were thought to be large enough for processing and statistical averaging but small enough to not disrupt the following year's growth. The areas were divided into a grid with 14 x 5 divisions, from which 3 sample locations from each of the 4 replicate sites on the 2 sides were randomly determined, for a total of 24 biomass samples.

A sampling square was constructed from 1/2" PVC pipe and 90 degree elbows. One PVC grid was used for all of the biomass samples to ensure consistency in sample area sizes. The biomass samples were collected by placing the pipe grid over the sample location and arranging all of the plants with stems rooted within the grid up through the grid. Plants within the area were cut off roughly 3/4" above the ground surface with handheld scissors. The plant biomass samples were then placed in ziplock bags and labeled with the date, soil type, plot number, and sample number. All of the biomass samples were collected on one day at the end of the growth season. Erwin (1990) contends that above ground biomass may be measured with little error in herbaceous vegetation by replicate samples harvested randomly from a grid. This method is most

effective with annual vegetation, where little biomass is lost to decomposition during the growing season, as is the case in our experiment.

3.2.2.2 Moist Weight. The biomass samples were prepared for drying by wrapping in aluminum foil and labeling. For each of the 24 samples, first the piece of aluminum foil was weighed, then the biomass was wrapped in the foil, then the biomass plus aluminum foil were reweighed together, these values were recorded, then the biomass sample was labeled. The moist biomass weights were found by subtracting the foil weights from that of the wrapped samples.

3.2.2.3 Dry Weight. The samples were then placed in a laboratory drying oven at 100-105 °C for over 24 hours until the samples were dried to a constant weight. The samples were then removed and immediately weighed again. By calculating the mass lost in the drying process the moisture content of the biomass sample was determined. Dry weight is used as a consistent means of assessing biomass.

3.2.2.4 Organic Content (from Ash). After drying, each sample was milled to homogenize it. A small portion of each of these dried, ground biomass samples (approximately one gram) was used for ash determination. For this process, preformed aluminum sample tins were used. Similar to the sample preparation for drying, the labeled aluminum sample dish was first weighed alone, then roughly 1 gram of ground dry biomass sample was added as determined by weighing. The sample dishes were placed in larger 9" x 13" x 3" deep (22.86 cm x 33.02 cm x 7.62 cm) perforated aluminum trays, 12 to a tray. The samples were then placed in the kiln at 500°C for 24 hours. At this temperature all of the volatile organics in the biomass sample were completely burned off.

Ashed samples were weighed immediately after removal to prevent regaining moisture. By subtracting the final ashed weight from the initial sample weight, the organic content of the biomass sample was determined.

3.2.2.5 Phosphate Content (from Ash). To determine the phosphate, PO_4^{3-}, content of the biomass samples, the 1.00 - 2.00 g of the ash, as obtained as described above, was suspended in 60 ml of distilled H_2O. The exact weight of the sample was recorded. For smaller samples the weight and volume were reduced accordingly. For example, 0.2 grams of ashed sample in 6.0 ml of H_2O. Then 6 ml of 5.25 Normal H_2SO_4 (Sulfuric Acid) from Hach test kit was added to the suspension.

The beaker was covered with watchglass and heated to a slow boil for about 10 minutes, taking care not to boil to dryness. The sample was allowed to cool before proceeding on to the next step. Small samples could be done in loosely covered (foil) test tubes and placed in 100-105 degree oven for 20 minutes.

Six (6) ml of 5 Normal NaOH from Hach kit was added to the cooled sample. Prewashed Whatman #1 filter paper was then used to filter the sample. The filtered sample was then vacuumed to dryness. Excess was transferred using rubber policeman and distilled H_2O. The filter paper and any solids on it were discarded.

The filtered and dried volume was brought to minimum of 20 ml with distilled H_2O, and the exact volume was recorded. The Hach Orthophosphate test (PO-19) was run in the low range, using 25 ml sample reageant packet.

3.2.2.5.1 Phosphate Calculations. The phosphate concentration represents only the diluted sample. The phosphate [mg/l] is multiplied by the volume to yield the amount of phosphate in the subsample which was diluted.

V = volume (total # mls in subsample before adding the PO_4^{3-} reagent for analysis

Sp = (mg reported per ml)(V in ml). Call this the subsample phosphate
Sp = Amount of phosphate in the sample of ash in mg (subsample)
Wo = Original weight of the sample before ash
Wa = Weight after ashing
Wo - Wa/Wo = Portion of weight which is organic (volatile at 500 °C)
Wo = Weight of original sample {g dry weight}
Ws = Weight of subsample before ashing {g dry weight}
Wo/Ws = Multiplication factor to correct for subsample {unitless constant}

(Wo/Ws)(Sp) = mg PO_4^{3-} in original sample = mg PO_4^{3-} per gram dry wt of biomass

(Wo/Ws)(mg PO_4 reported)(V) = mg PO_4^{3-} in original sample = mg PO_4^{3-} per gram dry wt of biomass

3.2.3 Water Sampling. Wells installed in each of the four seed mixture areas on both the gravel and the hydric soil sides provide a source for water chemistry samples (Figure 3-4). The seed mixture areas were chosen as the site for the wells because it would best represent an overall comparison of water chemistry on the two substrates. It would also minimize any possible local water chemistry induced by individual plant species which might occur if the wells were located in the individual seeded, greenhouse grown, natural wetland plug, or *Epilobium coloratum* areas. It was also judged that the wells could be disruptive in the individual seeded or greenhouse areas.

At each of these locations two wells were placed: one gathering water from the top 6" (15.24 cm) of soil and a second one from the 6"(15.24 cm) below that, the gravel layer underlying both sides (Figure 3-7). Each well consisted of a 1 1/2" diameter PVC pipe with an endcap on the end placed into the ground and 5 slots, hand cut into the pipe with a rotary saw. The pipes or wells with screens accessing the two different depths were cut to different lengths to distinguish between the lower underlying gravel layer and the upper experimental topsoil layer gravel or soil. The tall pipes correspond to the lower depth and the short pipes correspond to the upper topsoil level. The bottom 6" of the wells for the upper topsoil level were filled with sand so that water would not collect in the bottom of the wells below the upper topsoil layer.

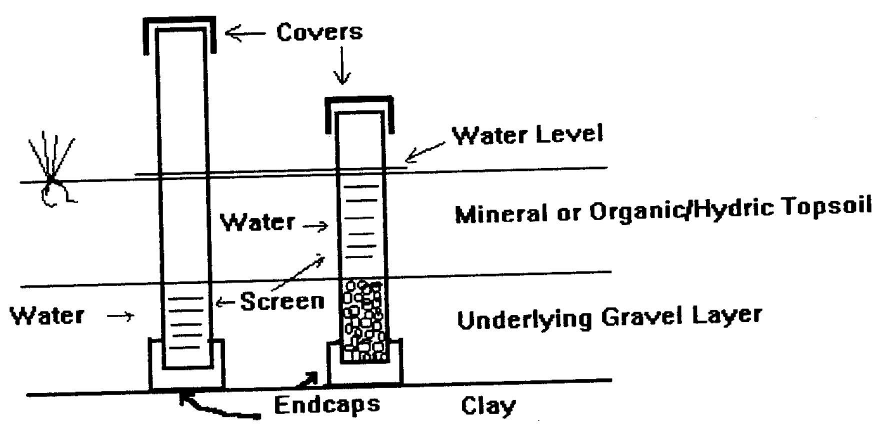


Figure 3-7 - Cross-sectional View of the Wells

Water samples were gathered from the site wells using a hand vacuum pump. Gerloff and Krombholz (1966) and Bayly et al. (1985) assert that porewater concentrations of nutrients were a valid proxy for nutrient availability. Between samples the holding container was rinsed out with water from the artesian well at the site. After each sample was gathered the sample was placed in a portable cooler for holding in transport back to the laboratory. Prior to their use, the water sample containers were prepared by first washing them in soapy water, then rinsing them out with 0.1 N HCl, and then triple rinsing them with distilled water. The water samples were stored in a refrigerator at the laboratory until they were analyzed.

Weirs were installed in the exit ditches of both soil and gravel sides. The weirs enabled "clean" water samples to be taken without gathering sediment in the samples and measure flow rates. A spigot on the artesian well allowed easy access to taking water samples from the well. Water samples were taken at three intervals (10 Jul 95, 24 Jul 95, 9 Aug 95) during the experiment.

The variations in levels of standing water on the site surface were also noted in the form of topography mapping in which a subjective 1, 2, or 3 representing low to high ground levels were given to areas. This data may help account for any differences between the four replicates in the same soil type.

3.3 DATA ANALYSES METHODOLOGY.

3.3.1 Greenhouse Growth Data.

3.3.1.1 Modified Height Data. Thirty-three (33) species were planted from greenhouse stock. Height data was collected and analyzed. The differences between the individual height measurements of the species growing on the gravel substrate compared to height measurements of the same species growing on the Westland silty clay loam substrate were calculated. Real zeros, representing the species absence from the particular plot due to failure to grow, death, or grazing were included in the difference calculations. Thus, the height differences is referred to as "modified height data", because in addition to being a function of purely height, the differences include plot germination rate and survival rate for the species. Real zeros were encompassed in the difference calculations to reflect an overall function of how well a species germinates (per plot), grows, and survives.

One-sided p-values were determined to indicate whether the modified height data for each species from the greenhouse stock planted on the gravel substrate was statistically different from the data planted on the Westland silty clay loam substrate. Devore (1991) gives a rule of thumb, if sample size (n) is greater than 30, then the Central Limit Theorem can be invoked, and the sample size assumed normal and the t-test therefore valid for the data set. Since there was a maximum of only twenty-four data points for each greenhouse data sets, it was not possible to apply Devore's rule of thumb. As an alternative, the Wilk-Shapiro test was performed on the set of modified height differences

to determine if the set was normally distributed and thus if the t-test was a valid means of determining the p-value for that species.

A rankit plot of each modified height difference data set was produced and an approximate Wilk-Shapiro normality statistic, the Shapiro-Francia statistic, was calculated using the Wilk-Shapiro/Rankit Plot procedure with the STATISTIX 4.0 (1995) software package. The test works on the principle that if the assumptions of linear regression are met, the standardized residuals should be approximately normally distributed with mean 0 (zero) and variance 1 (one). The i-th rankit was defined as the expected value of the i-th order statistic for the sample, assuming the sample was from a normal distribution. The order statistics of a sample are the sample values reordered by their rank. If the sample conforms to a normal distribution, a plot of the rankits against the order statistics should result in a straight line, except for random variation (example in Appendix B). The approximate Wilk-Shapiro (WS) statistic calculated is the square of the linear correlation between the rankits and the order statistics. If the rankit plot appears not to be a straight line, or if the Wilk-Shapiro (WS) statistic is a small value then the data is not normally distributed. A WS=0.8 is generally a good minimum value indicating normality (Reynolds, 1995), thus a WS<0.8 was used as an indication of non-normality, while a WS≥0.8 was deemed to indicate normality (Summary of WS Values in Appendix C).

If the data for the individual species planted from greenhouse stock was determined to be normal (WS≥0.8) then the one-sided p-value of the set of modified height differences for each species planted from greenhouse stock. The "direction" of the p-value was also noted. Thus, it was determined if the two distributions were different

which was greater on average, indicating which substrate better supported growth as reflected in the modified height data. If the data was determined to be non-normal (WS<0.8) then the nonparametric alternative to the paired t-test, the Wilcoxon Signed Rank test is performed on the modified height data. A paired t-test is used when there is only one set of n individuals or experimental objects, and two observations are made on each individual or object (Devore, 1991:347). When doing the paired t-test the following assumptions are made: The data consists of n independently selected pairs (X_1, Y_1), (X_2, Y_2), ..., (X_n, Y_n), with the expected value of X equal to the mean of X, $E(X_i) = \mu_1$, and the expected value of Y equal to the mean of Y, $E(Y_i) = \mu_2$. The D_i's are the differences within pairs, where $D_1 = X_1 - Y_1$, $D_2 = X_2 - Y_2$, ..., $D_n = X_n - Y_n$. Then the D_i's are assumed to be normally distributed with variance σ^2_D. This is usually a consequence of the X_i's and Y_i's themselves being normally distributed (Devore, 1991).

Because different data pairs are independent, the D_i's are independent of one another. If we let D = X - Y, where X and Y are the first and second observation, respectively, within an arbitrary pair, then the expected difference is

$$\mu_D = E(X - Y) = E(X) - E(Y) = \mu_1 - \mu_2$$

(the rule of expected values is valid even when X and Y are dependent). Thus any hypothesis about $\mu_1 - \mu_2$ can be phrased as a hypothesis about the mean difference μ_D. But since the D_i's constitute a normal random sample (of differences)with mean u_D, hypotheses about μ_D can be tested using a one-sample t test. To test hypotheses about $\mu_1 - \mu_2$ when data is paired, form the differences $D_1, D_2, \ldots, D_n$ and carry out a one-sample *t* test (based on *n*-1 degrees of freedom) on the differences (Devore, 1991:349).

Null hypothesis: H_o: $\mu_D=\Delta_o$ (where D=X-Y is the difference between the first and second observations within a pair ($\mu_D=\mu_1-\mu_2$)).

Test statistic value: $t_{paired} = \frac{\text{dbar} - \Delta o}{s_D/(n)^{1/2}}$ (where dbar and s_D are the sample mean and standard deviation, respectively, of the d_i's)

Alternative hypothesis	Rejection region for level α test
H_a: $\mu_D > \Delta_o$	$t_{paired} >= t_{\alpha,n-1}$
H_a: $\mu_D < \Delta_o$	$t_{paired} <= -t_{\alpha,n-1}$
H_a: $\mu_D <> \Delta_o$	either $t_{paired} >= t_{\alpha/2,n-1}$ or $t_{paired} <= -t_{\alpha/2,n-1}$

This paired test is valid even if $\sigma^2_1 <> \sigma^2_2$, since the differences are still normally distributed and s^2_D estimates $\sigma^2_D = V(X-Y)$. While a two-sample *t* test would be based on 2 *n* - 2 degrees of freedom (d.f.), the paired *t* test uses only *n*-1 d.f. To ensure a correct analysis, we give up *n*-1 degrees of freedom. (Devore, 1991)

In the cases where the data was determined to be non-normal (WS<0.8) then the Wilcoxon Signed Rank Test routine in the STATISTIX 4.0 (1995) software package, a nonparametric alternative to the paired t-test, was employed to determine the one-sided p-values. The one-sided p-value and its direction indicated which substrate supports growth better as reflected by the modified height data.

The Wilcoxon Signed Rank Test is more accurate than the Sign Test, because the Wilcoxon Signed Rank Test (WSRT) takes into account the magnitudes of the observations as well as the sign of each observation, whereas, the Sign Test discards these magnitudes. The underlying distribution the WSRT is applied to is assumed symmetric, $\mu=\mu_o$, so the hypotheses of interest are stated in terms of μ rather than μ^*. When doing the WSRT it is assumed, $X_1, X_2, \ldots, X_n$ is a random sample from a continuous and symmetric probability distribution with mean (and median) μ. When the hypothesized

value of μ is μ_o, the absolute differences $/x_1-\mu_o/,\ldots,/x_n-\mu_o/$ must be ranked from smallest to largest.

Null hypothesis: H_o: $\mu=\mu_o$

Test statistic value: s_+ = the sum of the ranks associated with positive $(x_i-\mu_o)$'s

Alternative hypothesis	Rejection region for level α test
H_a: $\mu>\mu_o$	$s_+ \geq c_1$
H_a: $\mu<\mu_o$	$s_+ \leq c2$ [where $c_2=n(n-1)/2-c_1$]
H_a: $\mu\neq\mu_o$	either $s_+ \geq c$ or $s_+ \leq n(n+1)/2-c$

where the critical values c_1 and c are obtained from tables such as the one in Appendix Table A.9 of Devore (1991) and satisfy $P(S_+ \geq c_1) \cong \alpha$ and $P(S_+ \geq c) \cong \alpha/2$ when H_o is true.

The one-sided p-values as determined by the paired t-test or the WSRT in the STATISTIX 4.0 (1995) software package were then ranked in levels of significance. The one-sided p-values were assigned ordinal values indicating the level of preference for a substrate type from high to low preference: 5 = p = 0.0000, 4 = p<0.0010, 3 = p<0.0100, 2 = p<0.1000, 1 = p<0.2000, and 0 = p≥0.2000 (no significant soil preference). The one-sided p-values were obtained by using the appropriate t-test or Wilcoxon Signed Rank test with the alternative hypothesis (presumption) that the plant species planted from greenhouse stock and from seed would prosper better in the Westland silty clay loam substrate than in the gravel substrate, as evidenced by larger height values. Similarly, the alternative hypothesis for the greenhouse versus seed (planting method) test was the plant

species planted from greenhouse stock would prosper better, grow taller, than those planted from seed regardless of substrate. The values in **bold** type are those one-sided p-values for which the opposite trends were evidenced. These plant species either prospered better planted in gravel substrate rather than soil, or prospered better planted from seed than those from greenhouse stock. In addition to being presented in table format, the ordinal values assigned to the one-sided p-values were plotted in histogram form.

3.3.1.2 Average Maximum Height Over the Growing Season. For each species the average maximum height over the four plots throughout the growing season were calculated for the two substrates, soil and gravel. Real zeros representing plots which either did not germinate or did not survive were not included in these averages, thus the plot survival and plot germination rates were not factored into the averages. The average maximum height values for the different species were then presented in tabular form.

3.3.1.3 Species Plot Survival Rates. The maximum height data was analyzed to determine how many of the four plots (on each substrate) of each species planted from greenhouse stock survived through the entire sampling period of the growing season. Height measurements were recorded at six intervals corresponding to 5, 6, 7, 8, 9, and 11 weeks out from the planting date. The species survival rate is based not on the number of individual plants, but rather the presence or absence of the species in the four plots on each substrates. Since each of the four plots on each substrate were initially planted with the greenhouse species, the survival rate is based on the number of surviving plots divided by four. For example, if 4 of the plots of the individual species survived the

sampling period, then the survival rate would be 4/4 x 100% or 100%, likewise if only 1 plot survived the survival rate would be 1/4 x 100% or 25%.

3.3.2 Seed Species Growth Data.

3.3.2.1 Modified Height Data. The modified height data for the species as planted from seed, was handled similarly to the data from the greenhouse stock plots. The Wilk-Shapiro tests and the Rankit plots were used to determine if the data was normal and the parametric t-test could be applied or if the data was non-normal and the nonparametric Wilcoxon Signed Rank Test was more appropriate. One-sided p-values were calculated and ordinal significance rankings described for greenhouse data were also applied to the seed data. The p-values were presented in tabular form as well as in histogram form.

3.3.2.2 Average Maximum Height Over the Growing Season. The same method applied to the greenhouse data was applied to the seed data.

3.3.2.3 Species Plot Germination Rates. The seed species data had an added variable, germination, that the greenhouse data did not. It was not the intention of this experiment to perform a rigorous, controlled germination experiment. The number seeds planted in each plot can only be roughly estimated because of the seed stratification process, and the number of individual seedlings of each species were not measured, only the presence or absence of the species in the plot and the overall maximum height of those individuals present in the plot. Given these restrictions, we defined the "germination rate" for the purpose of this experiment as the percentage of plots planted in that species (out of four) which grew to a measurable/observable height during the sampling period sometime

prior to and including the last measurement in the 11th week after planting. For example, if 4 of the plots of the particular species had observable individuals, then the survival rate would be 4/4 x 100% or 100%, 3 plots = 75%, 2 plots = 50%, and 1 plot = 25%.

3.3.2.4 Species Plot Survival Rates. Since the species planted from seed also had a germination factor to contend with which the greenhouse plots did not, the species plot survival rate was calculated separately in an attempt to separate these two phenomena, both germination and survival. The species survival rates are calculated on the basis of how many plots of that species survived the season out of those plots which grew at all (germinated). For example, if 3 out of 4 plots of species 1 germinated and a total of 2 plots of those plots survived the season, then the survival rate for the species is 2 out of 3 or 66.66%.

3.3.3 Greenhouse Planting versus Seed Planting. The species were classified by their one-sided p-values into a matrix which listed the substrate preference for each of the species given either planting from seed or from greenhouse grown plants. If the p-value did not indicate any significant difference between the two substrates, the substrate preference was deemed "not significant" or NS for that planting method and species.

3.3.4 Natural Wetland Transplanted Plugs. The 20 plugs represented different combinations of wetland vegetation. The plugs by their very nature contained more than one species per plug. The maximum height of various prominent species in the plugs were recorded (Appendix E) and compiled on four occasions: 13 Jul 95, 22 Jul 95, 3 Aug 95, and 24 Aug 95, or in Julian date on days 194, 203, 215, and 236. The species observed and measured in the twenty plugs were compiled and listed in Table 3-1.

Since the individual plants were of different heights at the time of their transplanting, to compare average maximum height or modified maximum height would not yield meaningful insight into the impact of substrate on the growth of species transplanted from natural wetlands. The growth patterns of different transplanted species, and more specifically, their growth rates, were decided to be of greater interest. To get at these growth patterns, scatter plots were produced for the species with enough observations for comparison (13 species). For each species, a scatter plot encompassing the data from plots 1, 2, 3, and 4 was produced with regression fits for the soil substrate and the gravel substrate overall. In addition, for each species, scatter plots displayed regression fits for data from separate plots and even from separate plugs within the same plot, which illustrate the cause of the large spread of the plug species height data. Growth curve slopes or growth rates (in/day) were calculated for the plugs growing on the gravel and soil substrates using the Linear Regression function of the STATISTIX 4.0 software package. These growth rates for the thirteen species were presented in tabular form and also plotted in the form of error bar plot further illustrating the differences in the growth rates of the species between the two substrates.

Table 3-1 Species Recorded in the Natural Plugs

PLUG#	SPECIES
1	*Eupatorium perfoliatum* (Boneset)
1	*Carex sp* (Sedge)
1	*Scirpus Atrovirens* (Green Bulrush)
2	*Eleocharis* sp (Spikerush)
2	*Carex* sp (Sedge)
2	*Mentha* sp (Mint)
2	*Eupatorium perfoliatum* (Boneset)
3	*Carex stricta* (tussock sedge)
4	*Eupatorium perfoliatum* (Boneset)
4	*Carex frankii* (Frank's Sedge)
4	*Aster* (Aster sp)
4	*Scirpus Atrovirens* (Green Bulrush)
5	*Eupatorium perfoliatum* (Boneset)
5	*Carex cristatella (Crested Sedge)*
5	Rice cut grass
5	*Eleocharis* sp (Spikerush)
6	*Iris* sp (Iris)
7	Rice cut grass
7	*Acorus calamus* (Sweetflag)
8	*Bidens* sp (Beggar-Ticks)
10	*Acorus calamus* (Sweetflag)
10	*Eupatorium perfoliatum* (Boneset)
10	*Eleocharis* sp (Spikerush)
11	Rice Cut Grass
11	*Juncus articulatus* (Jointed Rush)
12	*Bidens* sp (Beggar-Ticks)
12	*Carex frankii* (Frank's Sedge)
12	*Aster* (Aster sp)
13	Queen of the Prairie
13	*Aster* (Aster sp)
13	*Iris* sp (Iris)
14	*Sanguisorba canadensis* (Canada Burnet)
15	*Juncus torreyii* (Torrey's Rush)
15	*Cyperus* sp (Flatsedge)
15	*Carex stricta* (tussock sedge)
15	Fern sp
16	*Carex* sp (Sedge)
16	Rice Cut Grass
17	*Juncus articulatus (Jointed Rush)*
17	Rice Cut Grass
17	*Mentha* sp (Mint)
18	*Scirpus pendula* (Drooping Bulrush)
19	*Mentha* sp (Mint)
19	*Eleocharis* sp (Spikerush)
19	*Bidens* sp (Beggar-Ticks)
19	*Carex* sp (Sedge)
20	*Mentha* sp (Mint)
20	Rice cut grass
20	Eupatoriadelphus maculatus (Joe Pye)

3.3.5 Comparison of Biomass Data From Two Substrates. The raw data and the calculated biomass data were recorded in a table (Appendix D). Three biomass samples were taken from each of the four plots on the two substrates for a total of twelve values on each substrate. Scatter plots of the these points for the percent water content, biomass dry weight per area harvested (mg/m^2), percent organic content, and biomass phosphate were produced. The average of the three data sample values for each of the plots on the two substrates were calculated and plotted in bar graph form for the same parameters presented in the scatter plots.

3.3.6 Water Chemistry Data. The water samples were analyzed for iron, alkalinity, total hardness, Calcium hardness, Magnesium hardness, ammonia, sulfate, soluble phosphate, and nitrate using kits manufactured by Hach. Whatman pH indicator paper (type CF pH 4.5-10) was used to measure the pH. Hach TPTZ Iron Reagent Method, Model IR-21 Cat. # 22993-00), for the range 0.0-0.20 mg/L, was used to analyze total iron (Fe). Total (methyl-orange) alkalinity in g/g as $CaCO_3$ or mg/L was measured using the low range instructions in the titration based Hach Model AL-AP (Cat. # 24443-00) test. Total, Calcium, and Magnesium hardness were analyzed using the titration-based Hach Model HA-4P (Cat. # 1457-00) test. The mg/L of ammonia nitrogen (N) or alternatively the mg/L ammonia (NH_3^-) or the mg/L ammonium ion (NH_4) were determined by the colormetric or "color wheel" Hach Model NI-8 (Cat. # 2241-00) test which used the Nessler Reagent. Sulfate (SO_4^{-2}) in mg/L was determined using Hach DR100 Colorimeter, Model 41100-19 test kit which was valid over the range of 0-80 mg/L. The Hach Orthophosphate test kit, Model PO-19A for turbid water (Cat. # 2248-

01), was used to determine the amount of phosphate (PO_4^{3-}) present in mg/L. The Hach Orthophosphate test kit entails a colorometric determination.

Water samples were taken in three trials - 10 Jul 95, 24 Jul 95, and 9 Aug 95, for the four plots on each substrate from two different soil depths. The data for the water samples from the upper 0"-6" of substrate was presented in one table and the data from the lower 6"-12" in another table. Bar plots for each of the chemical parameters, i.e. pH, iron, etc. were produced. The bar plots presented data side by side for the two substrates and two soil depths within each of them. Wilk-Shapiro and Rankit plots were used to determine the normality of the individual chemical parameter distribution, and the appropriateness of the t-test or the Wilcoxon Signed Rank test. Two-sided and one-sided p-values were then calculated using the appropriate tests and presented in tabular form. Regular type was used to indicate the trend for the chemical parameter to be higher on the soil side than on the gravel side, whereas, bold type indicates the opposite trend. The p-value 0.0000 indicates that the two data series are almost definitely <u>not</u> the same, while the p-value 1.0000 indicates the two data series are almost definitely from the <u>same</u> series.

3.3.7 Substrate Surface "Moisture" Contour Plots. Contour plots indicating varying levels of soil moisture and even standing water in the four greenhouse plots and the four seed plots for the two substrates were sketched from purely visual observation on 28 Jun 95. This data was considered observational rather than experimental. We were interested in how the moisture degrees may have impacted the greenhouse and seed species growth in the different plots on the same substrate, possibly causing the variance in growth and even water chemistry values within the same substrate.

The contour plots constructed were labeled on the scale of Deepest, Deeper, Less Deep/Deep, Moist, and Dry. Because the original contours did not follow the grid of areas set aside for each seed or greenhouse species, an expanded scale was applied and a value for each of the species areas (twenty areas per plot - accounting for 33 species per plot because 13 of the species are planted a top each other). The scale is as follows:

Dry:	(13) 75-100% Dry (<25% Moist)
	(12) 50-75% Dry
	(11) < 50% Dry (50+% Moist)
Moist:	(10) 75-100% Moist
	(9) 50-75% Moist
	(8) <50% Moist (50+% Deep/Less Deep)
Deep:	(7) 75-100% Deep
	(6) 50-75% Deep
	(5) <50% Deep
Deeper:	(4) 75-100% Deeper (<25% Deepest)
	(3) 50-75% (25-50% Deepest)
	(2) 25-50% (50-75% Deepest)
	(1) 75-100% Deepest (<25% Deeper)

Judgment was used in applying these values because sometimes several conditions existed within the same planting area ("block"). Once these values were assigned, additional moisture contour plots reflecting these values were produced for soil and greenhouse plots on soil and gravel substrates. The lower values indicating wetter conditions, are represented in the gray scale as darker areas. The plots are labeled simply, for example, "Soilseedplot3" means plot 3 in the area planted from seed on the soil substrate, while "Gravelgreenhsplot4" means plot 4 in the area planted from greenhouse stock on the gravel substrate.

4.0 RESULTS AND DISCUSSION

4.1 GREENHOUSE STOCK.

4.1.1 Modified Maximum Height Data for Species Planted

From Greenhouse Stock. Of the thirty-three species were planted from greenhouse stock seven species failed to grow in either soil or till substrate: *Pedicularis lanceolata* (#3), *Potentilla fruticosa* (#11), *Pycnanthemum* (#16), *Gentiana clausa* (#17), *Lobelia cardinalis* , (#21), *Physostegia* , and *Thelypteris Thelypteroides* (#29) in this first year. The cause or meaning of this failure is unclear at this point. It is possible that the species did germinate and grow but because of their small size went unobserved. *Thelypteris Thelypteroides* (Marsh ferns), for example, would not be expected to develop to visible level until the second year. The species may have failed to germinate in the first year, but may subsequently germinate next year or in following years. The conditions, including light, moisture, etc. may not have been conducive to the species germination so the species may have remained dormant. It is unlikely the method of stratification and storage caused the seed to be nonviable, because these species of seed have been successfully grown in the past using this methodology (Amon, 1995). In addition, the seed for these species was treated in a manner consistent with the other species which did germinate.

Height data for each of the remaining twenty-five species was analyzed. The differences between the individual height measurements of the species growing on the gravel substrate compared to height measurements of the same species growing on the soil substrate were calculated. For each species the Wilk-Shapiro test was performed on the

set of differences to determine if the set was normally distributed (WS≥0.8) and thus if the t-test was a valid means of determining the p-value for that species.

Wilk-Shapiro values (Appendix C) indicated that the t-test was valid (WS≥0.8) in 24 of the 25 viable greenhouse species datasets, with the exception of *Mentha* sp data for which the Wilcoxon Signed Rank test was required. Once the Wilk-Shapiro values were obtained, the 1-tail p-values (Appendix F) were determined by applying the appropriate t-test or Wilcoxon Signed Rank tests.

The response of greenhouse grown plants to the wetland substrate is shown in Figure 4-1. The figure depicts the significance of differences in growth based on height using an ordination of one-sided p-values associated with these differences (raw p-values in Appendix F). Positive values indicate that the plants growth response fit the hypothesis that soil was a better substrate than till. Negative values indicate the growth response of the plants was best on the gravelly till.

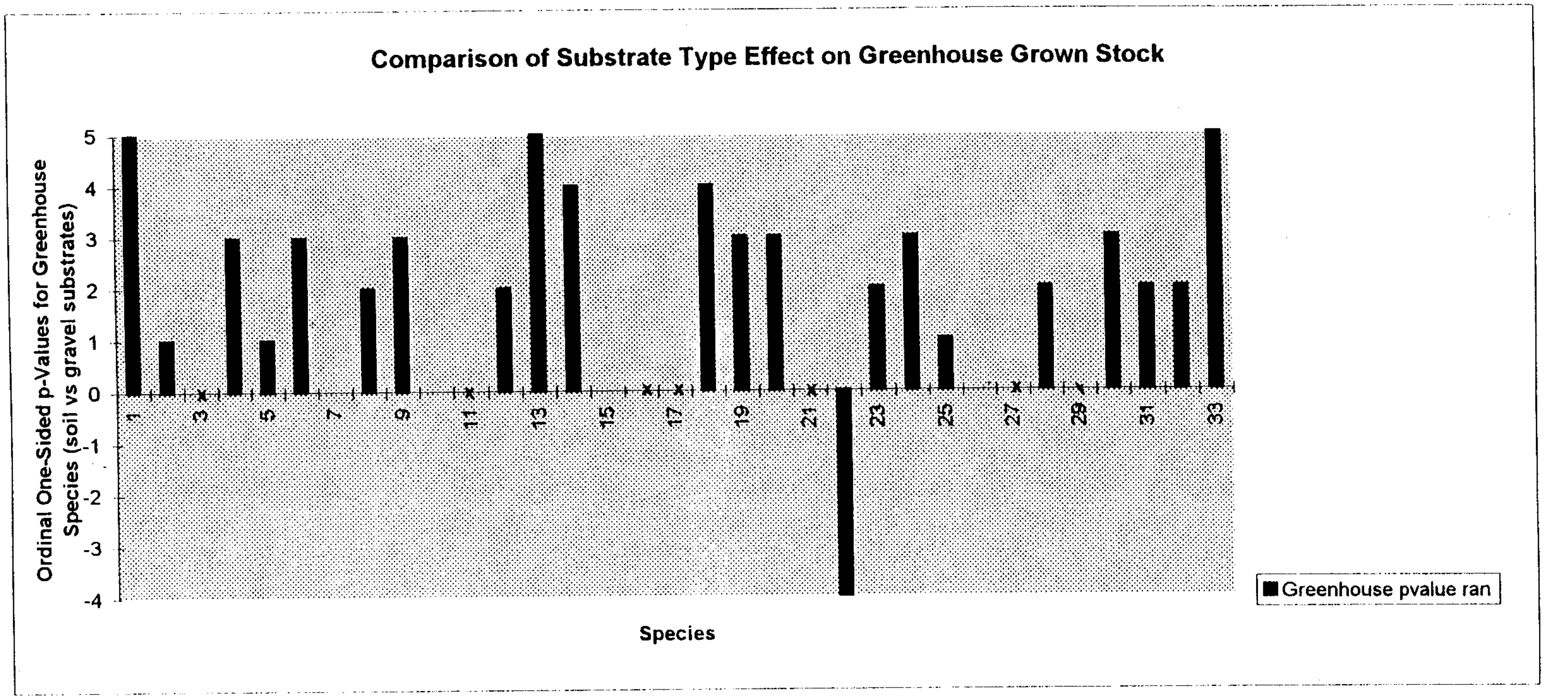


Figure 4 - 1 -- Comparison of Modified Height on Species Planted from Greenhouse Stock on Gravel vs Soil Substrates (Using One-Sided p-Values)

Interpretive Key: Bar Height indicates <u>strength</u> of preference, (+) value indicates <u>preference for soil</u>, and (-) indicates <u>preference for gravel till</u>

<u>Species Key</u>

1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

Chelone glabra (#10), *Carex lupuliformis* (#7), and *Sanguisorba canadensis* (#26) showed no preference for either substrate and one of the mint species (#22) died on the soil substrate but did survive on the gravel till. Greenhouse stock for these species survive in both substrates, but grew taller on the soil substrate compared to the gravel substrate. All other species showed varying levels of preference for the hydric soil. Two greenhouses species, *Carex frankii* (#14) and *Asclepias incarnata* (#18), showed somewhat less strong preference for soil (+4). Notably, out of the species which showed a substrate preference, *Carex lurida* (#5) and *Carex cristatella* (#25) showed the weakest preference for soil substrate (+1).

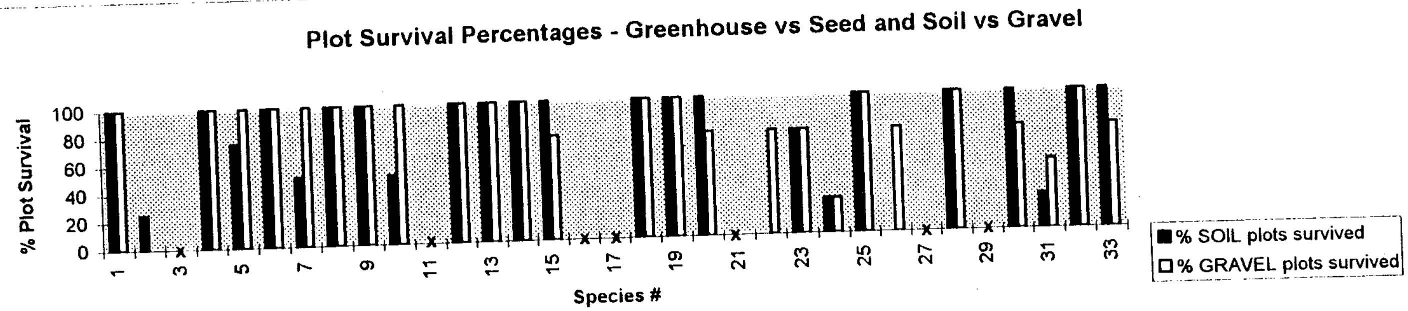
In general, the greenhouse generated plantings grew well on both substrates and increased their height by about 2 to 5 times. In addition to increases in height many of the plants spread laterally but this growth was not quantified.

4.1.2 Survival of Species Planted From Greenhouse Stock. The survival of greenhouse grown plants through the first growing season is shown in Figure 4-2 (% of plots survived). Seven species were either not planted on both sides from greenhouse stock or were planted and subsequently failed to survive on either substrate: (#3) - *Pedicularis lanceolata,* (#11) - *Potentilla fruticosa* , (#16) - *Pycnanthemum,* (#17) - *Gentiana clausa,* (#21) - *Lobelia cardinalis,* (#27) - *Physostegia* , and (#29) - *Thelypteris Thelypteroides*. Of the remaining 26 species planted from greenhouse stock, 15 of them had identical survival rates on both types of substrate. Five species survived better on the soil side than the gravel side: #2 - *Mentha* sp, #15 - *Filipendula rubra* (Queen of the Prairie), #20 - *Juncus torreyi*, #30 - *Scirpus validus*, and #33 - *Solidago riddlii* (Riddlii's

goldenrod). Six species actually had higher survival rates on the gravel substrate than on the soil substrate: #5 - *Carex lurida*, #7 - *Carex lupuliformis* , #10 - *Chelone glabra*, #22 - *Mentha* sp 2, #26 - *Sanguisorba canadensis*, and #31 - *Verbena hastada*.

In general, the greenhouse grown plants had high survival rates in both substrates, often 100% or all 4 plots survived. Low survival rates were observed for *Mentha* sp (#2), *Mentha* 3 sp (#24), and *Verbena hastada* (#31). The majority of species survived equally on the soil and the gravel till during the first year.

Although it is unexpected that some (five) species exhibited a higher survival rate on the gravel till than the soil, it is not totally unreasonable. While one would expect species native to fens to be adapted to survival on hydric soil, other environmental factors besides soil may have influenced the survival rates. Increased moisture levels, and decreased competition for space and light because of the lower density of vegetation on the gravel side may have accounted for the higher survival rates on the gravel substrate.



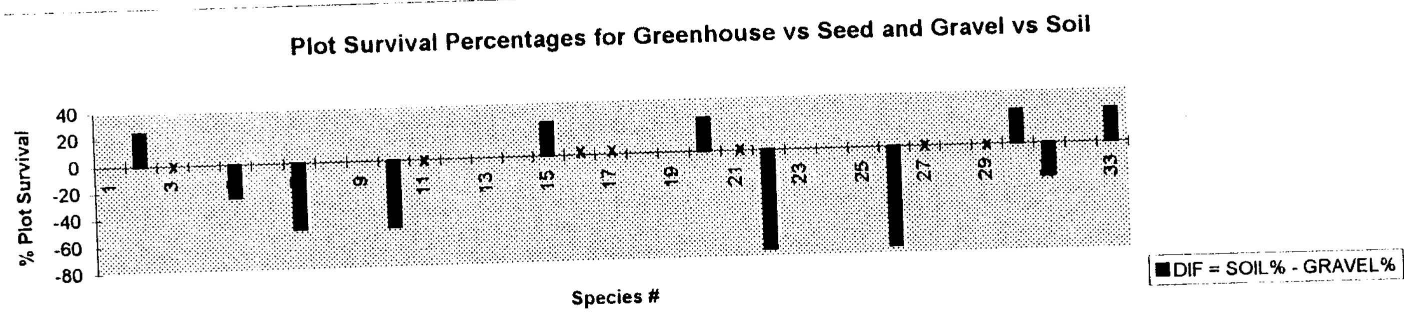


Figure 4-2 Survival of Greenhouse Stock on Soil vs Gravel

Interpretive Key: Bar Height indicates strength of preference, (+) value indicates preference for soil, and (-) indicates preference for gravel till

Species Key
1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

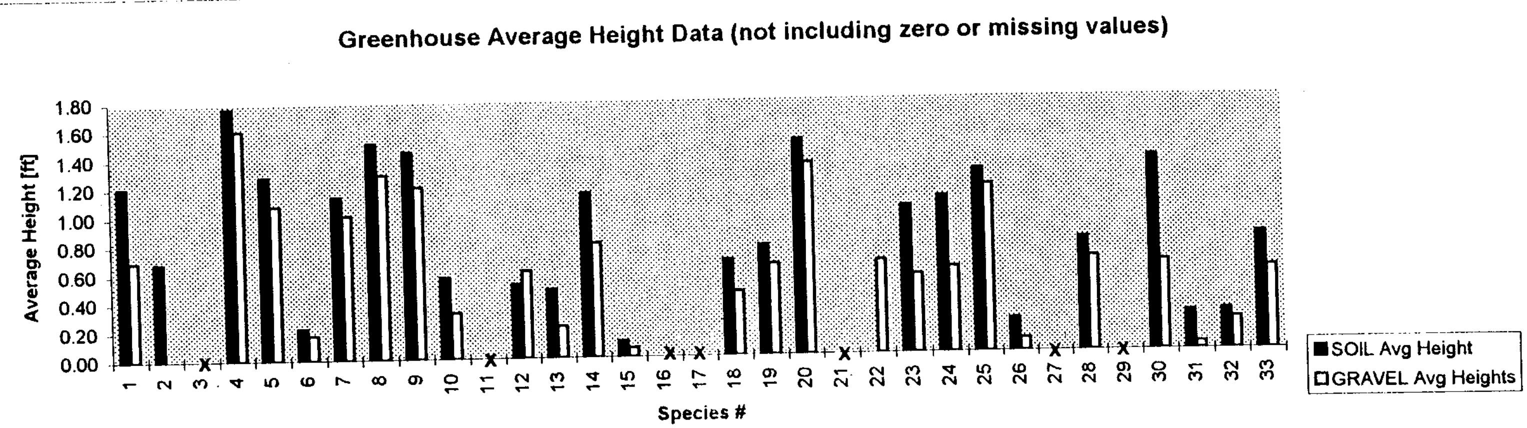
4.1.3 Average Maximum Plot Height for Species Planted From Greenhouse Stock (not including zero or missing values). The average maximum plot height of greenhouse grown plants on the two substrates through the first growing season is shown in Figure 4-3. The upper plot shows the average height data (ft) for the 33 species on the two substrates side by side. Looking at the upper plot we can tell the relative height difference between the two substrates, while the lower plot gives a simpler illustrates the magnitude of the height difference. The height difference values in the lower plot were calculated by subtracting the gravel average height from the soil height. Therefore, positive values on the lower plot indicate the species grew taller on average on the soil substrate, while negative values indicate the species grew taller on the gravel till.

In the lower plot in Figure 4-3, almost unanimously species planted from greenhouse stock grew taller on the soil substrate than on the gravel substrate with the exception of three species. *Mentha* sp 2 (#22) failed to grow on the soil substrate, but did grow to an average 0.65 ft (~7.8") on the gravel till. Two other species, *Eupatoriadelphus maculatus* (#12) and *Angelica atropurpurea* (#32) were 0.09 ft (~1.08") and 0.04 ft (~0.5") on average (~14%) shorter on the soil substrate than on the gravel substrate (Figure 4-3).

In the upper plot in Figure 4-3, the relative height difference was not dramatic for most species, but for a few species it was significant. *Carex hystricina* (#1), *Filipendula rubra* (#15), *Carex prairea* (#23), *Mentha* sp 3 (#24), *Scirpus validus* (#30), and *Verbena hastada* (#31) show the greatest relative height preference for soil. For example,

Filipendula rubra grew twice as tall and *Verbena hastada* five times as tall on soil as on gravel till.

In general, most greenhouse grown plants grew better on the soil than on the gravel till. This absolute and relative difference in average height, could be significant because the species may be outcompeted by other planted species or by invading species for sunlight if they are shorter, especially during the first growing season. The shorter height is also one indication of plant species success. As will be discussed in section 4.8, the nutrient supply and water chemistry in the root zone and below that is basically the same for the soil and the gravel till. Therefore, it appears more likely that the difference in the growth is due to the presence of microbes in the soil which may facilitate nutrient uptake in the plants. This was not a controlled factor in our experiment so we cannot make a definite conclusion.



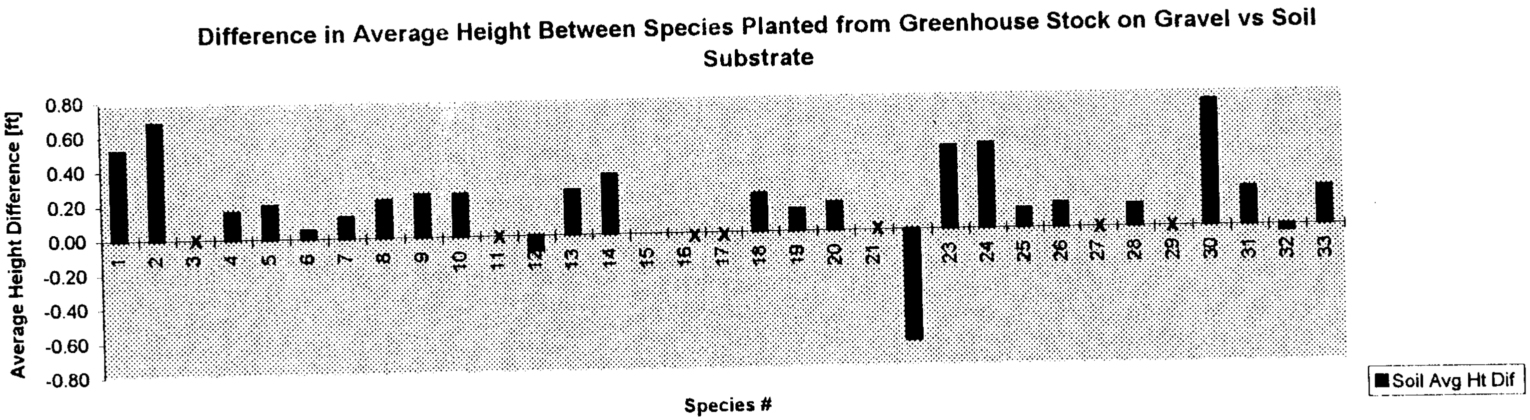


Figure 4-3 Average Maximum Plot Height for Species Planted From Greenhouse Stock

Species Key

1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

4.2 FOCUS QUESTION 2 - SUCCESS OF SPECIES PLANTED FROM SEED.

4.2.1 Modified Height Data for Species Planted From Seed - Analyzed Using p-Values. Nine of the 33 species planted from seed failed to grow in either the gravel substrate or the Westland silty clay loam (hydric) substrate. The Wilcoxon Signed Rank test was indicated by Wilk-Shapiro values (Appendix C) of less than 0.8 in 5 of the remaining 24 seed species datasets: (#10) *Chelone glabra*, (#24) *Mentha* 3 sp, (#26) *Sanguisorba canadensis*, (#31)*Verbena hastada*, and (#32) *Angelica atropurpurea*.

The response of plants grown from seed to the wetland substrate is shown in Figure 4-4. The figure depicts the significance of differences in growth based on height using an ordination of one-sided p-values associated with these differences (raw p-values in Appendix F). Positive values indicate that the plants growth response fit the hypothesis that soil was a better substrate than till. Negative values indicate the growth response of the plants was best on the gravelly till.

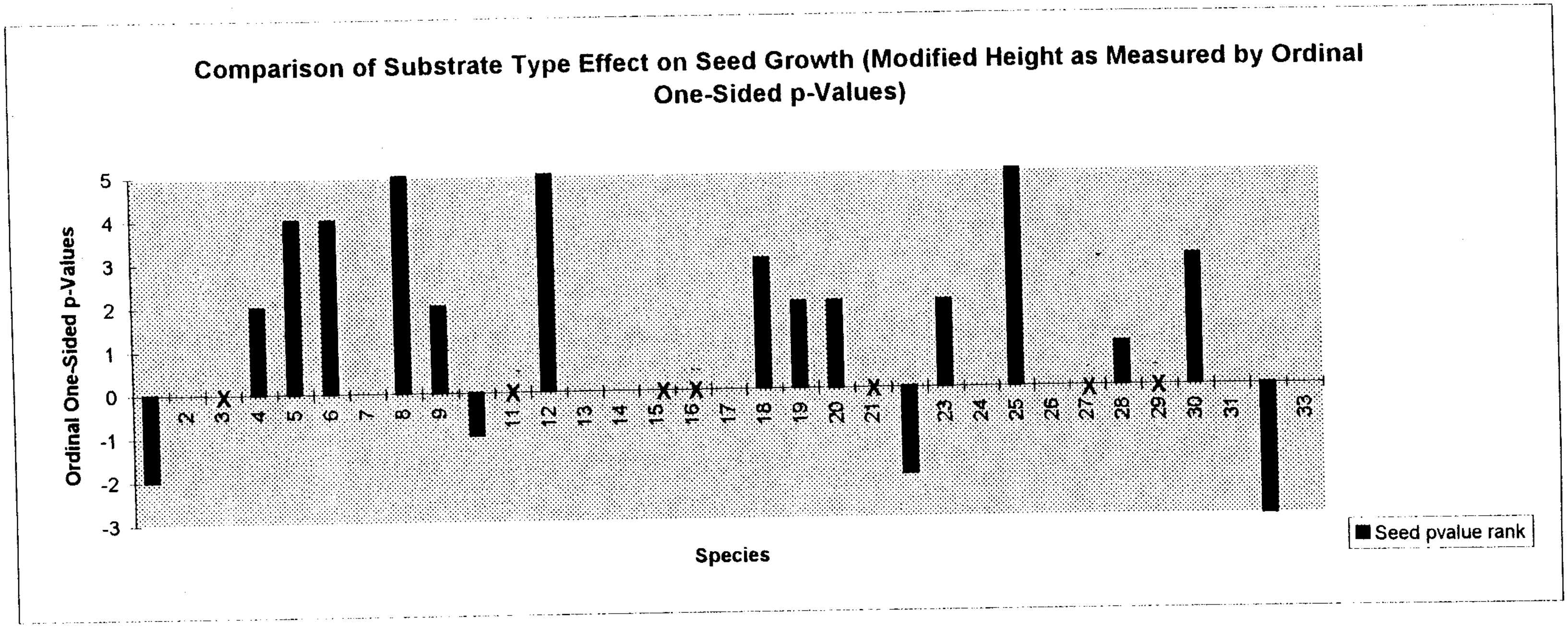


Figure 4- 4 -- Comparison of Substrate Effect on Species Planted from Seed (Modified Height as Measured by Ordinal One-Sided p-Values)

Interpretive Key: Bar Height indicates <u>strength</u> of preference; (+) value indicates <u>preference for soil;</u> and (-) value indicates <u>preference for gravel till</u>

<u>Species Key</u>

1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

From Figure 4-4 we see the vast majority of the species (21 of 33) planted from seed exhibited better growth to varying degrees on the soil substrate. Three species showed strong preference (+5) for the soil substrate. In the case of *Eupatoriadelphus maculatus* (#12), only one plant specimen grew on the gravel substrate and subsequently died, while the species survived and grew well on the soil substrate. *Carex stipata* (#8) and *Carex cristatella* (#25) seed data grew in both substrates, but was significantly more successful on the soil than the gravel till. *Carex lurida* and *Cacalia sauveolens* showed similar highly significant tendencies (+4). *Asclepias incarnata* (#18) and *Scirpus validus* (#30) have a less significant preference (+3) for soil substrate. The remaining 6 of the 21 species showed less dramatic preference (+2 and +1) for soil substrate.

Figure 4-4 also shows 7 of the 33 plant species grew equally well on soil and on gravel (+0) when planted from seed: (#2) *Mentha* sp, (#7) *Carex lupuliformis* , (#13). *Eupatorium perfoliatum* sp, (#14) *Carex Frankii,* (#24) *Mentha* 3 sp, (#26) *Sanguisorba canadensis, and* (#31) *Verbena hastada*. The scatter plots for these species also illustrate that the linear regression fits for the gravel seed data and the soil seed data for these species are not significantly different, nor is one regression line consistently significantly higher than the other (example Appendix G).

Five of the 33 plant species planted from seed prospered better in the gravel substrate: (32) *Angelica atropurpurea,* (#1) *Carex hystricina,* (#22) *Mentha* 2 sp, and (#10) *Chelone glabra*. *Angelica atropurpurea* showed a strong tendency (+3) to grow

taller in the gravel till than in the soil, while *Carex hystricina* and *Mentha* 2 sp showed less strong (+2), preferences, and *Chelone glabra* showed only a slight tendency (+1).

In general, while the vast majority of the species (21 of 33) planted from seed exhibited better growth on the soil substrate, seven species performed equally well on the gravel till as on the soil and five species even preferred the gravel till. This shows that species need to be considered on an individual basis, because each may react differently to the substrate change. No trends in which members of a species family all favored a particular soil type and to the same degree (same ordinal p-value) were found. Indeed, examining the data we found there was no agreement within the *Carex's* or within the *Mentha's*. We can speculate that it is indeed possible even plausible for species to favor soil, or perform equally, or favor gravel till, but we cannot predict this behavior without experimental testing similar to the test we conducted.

One might expect most of the species to perform better on the soil substrate, assuming the species would germinate, survive, and grow in height (all factoring into the p-value) better under conditions (substrate) most closely replicating that of the current natural wetland environment from which the seeds were gathered. Under this assumption, the fact seven species performed as well on gravel till as on soil and an additional five species performed better on the gravel till, could be perplexing.

Perhaps this result can be explained by reexamining our assumption. First, unlike our site, almost none of vegetation in local natural fens was established from seed in the last growing season. In fact, it is common for many fen species with the exception of annuals to only germinate from seed in locations where a disturbance has occurred

leaving a cleared or open area. Instead, most species (perennials) persist for numerous years with new herbaceous growth from the persisting root stock. These species often propagate vegetatively, sometimes sending out "runners". Thus, through perennial growth and vegetative propagation, a specimen germinated from seed may persist indefinitely for all practical purposes. It is therefore plausible that the individual plants present in the local natural fens may have originated from a seed which germinated hundreds even thousands of years ago, possibly even when the fen was first being established.

Andreas (1985) found ninety-three (82%) of 114 Ohio peatlands (fens or bogs)investigated occurred on or near buried pre-glacial river valleys. These buried river valley are filled with glacial till, a calcareous substrate similar to the gravel till used in this experiment. Thus, if the seed germinated thousands of years ago when the fen was still in its early successional stages, then the seed may have actually germinated on gravel till and fairly sparsely vegetated area. If this is the case, the seed from the plants in the local wetlands may actually be adapted to germinating on gravel till.

Furthermore, some species might also be adapted to prospering (surviving and growing taller) better in the more open areas available on the gravel side. Species planted on the gravel side also do not have to contend with vegetation from the seedbank competing for resources such as nutrients and light with the species planted from seed. Given this possible scenario, it is plausible some of the species could perform equally well or better on the gravel till compared to the soil.

4.2.2 Germination of Plots of Species Planted From Seed. The germination of the 4 plots a species growing from seed are displayed in Figure 4-5. The upper plot germination values (percentages) on the two substrates, while the lower plot shows the magnitude of difference between germination on the soil side and the gravel side.

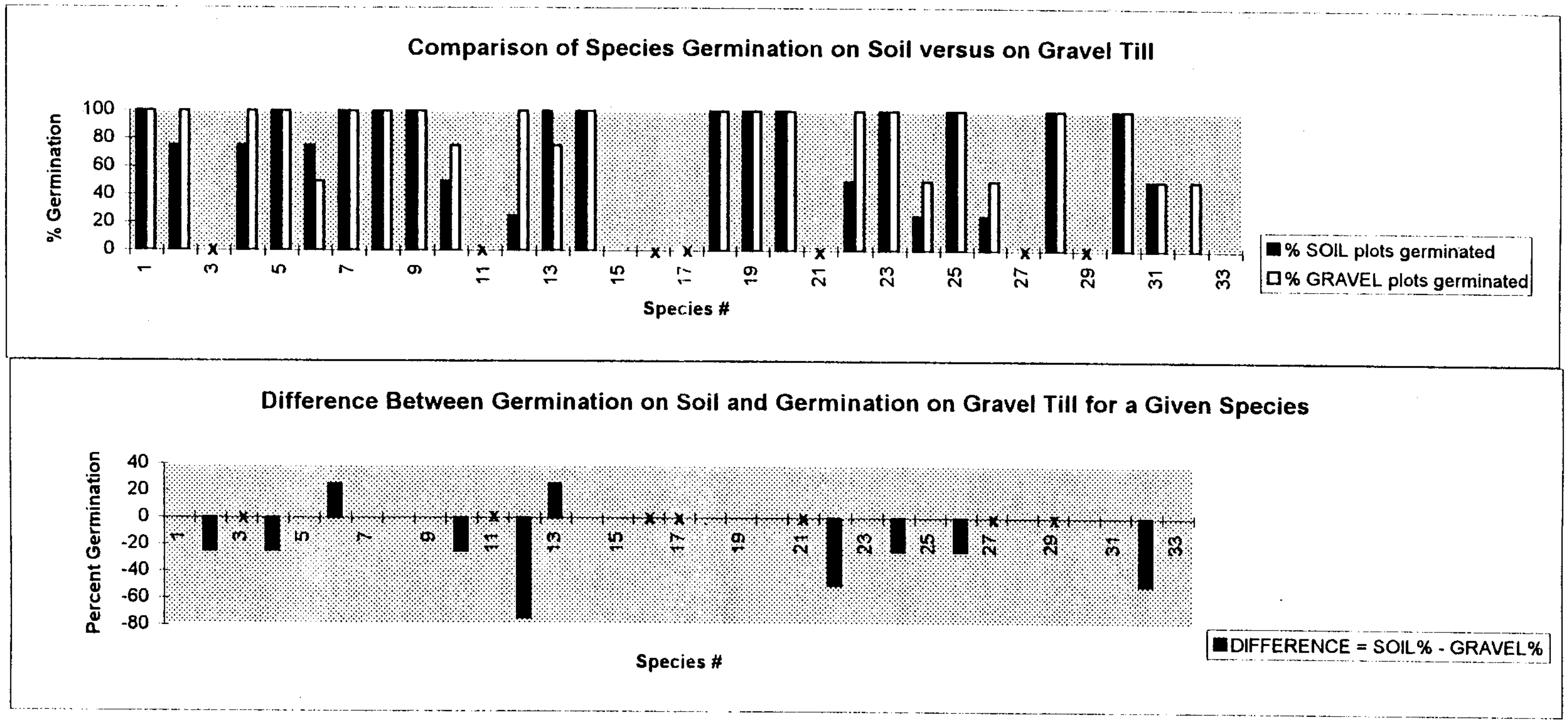


Figure 4-5 Comparison of Species Germination on Soil Substrate and on Gravel Till

<u>Interpretive Key:</u> <u>Top Plot</u> => Shows Relative Germination on the 2 Soils (% = #plots germinated/4 *100);
Bottom Plot => Illustrates Magnitude and Direction of the Impact of Substrate on Plot Germination;
(+) in Lower Plot indicates species <u>germinates better on soil. But (-) indicates germinates better on g</u>

<u>Species Key</u>
1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

Positive values in the lower plot indicate the species germinated better on the soil, while negative values indicate the species germinated better on the gravel till. From the upper plot on Figure 4-5 we see most species germinated successfully, however 9 of the 33 species failed to germinate on either the gravel or soil substrates. Germination of plots of species planted from seed shows that, in most cases (13 of 33), species germinated equally well on the soil substrate and on the gravel substrate (Figure 4-5). Two species experienced higher germination rates on the soil: *Cacalia sauveolens* (#6) and *Eupatorium perfoliatum* sp (#13). Some (8 of 33) species, however, exhibited greater plot germination rates on the gravel substrate including the following species: #2 - *Mentha* sp, #4 - *Carex stricta* (tussock sedge), #10 - *Chelone glabra*, #12 - *Eupatoriadelphus maculatus*, #22 - *Mentha* sp 2, #24 - *Mentha* sp 3, #26 - *Sanguisorba canadensis*, and #32 - *Angelica atropurpurea*.

In general, the two substrates supported successful germination of most species. Most species germinated equally on both substrates, but a couple species preferred soil and a notable number of species actually germinated better on the gravel substrate. Just as we found from the p-value results of the modified height, this shows us that the species need to be considered on an individual basis, because each may react differently to the substrate change. We did not find any trends in which members of a species family all favored a particular soil type and to the same degree (same ordinal p-value). For example, *Carex stricta* preferred gravel, while *Carex hystricina* (#1), *Carex lurida* (#5), *Carex lupuliformis* (#7), *Carex stipata* (#8), *Carex prairea* (#23), *and Carex cristatella* (#25) germinated equally well in the soil and in the gravel till. Based on the discussion in section

4.2.1 and the data in Figure 4-5, we can speculate that it is indeed possible even plausible for species to germinate better on soil, or perform equally on the two substrates, or germinate better on gravel till, but we cannot predict this behavior without experimental testing similar to the test we conducted.

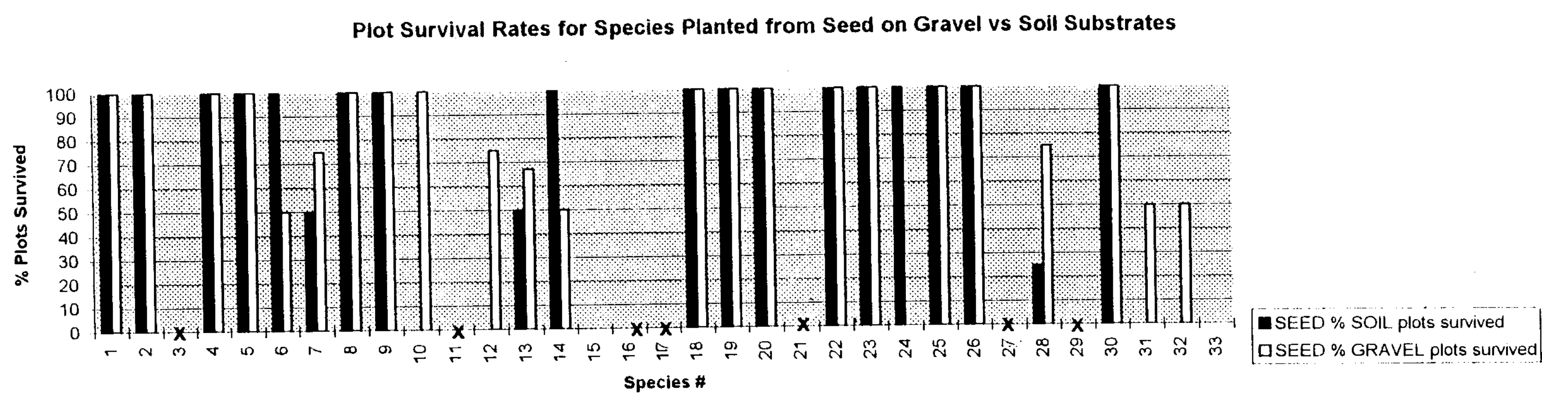
It should be noted that these rates are based on very small sample sizes of only 4 plots on each substrate. The site should be monitored over the next few years to determine if the nine (9) species which were determined to have failed to germinate on either substrate, germinate or alternatively grow to a detectable height in subsequent years. Laboratory testing of germination in subscale controlled greenhouse environments might also be helpful in further quantifying the effect of substrate type on species germination rates. However, while laboratory testing would provide a more controlled environment, interactions which may take place in the natural environment (outside) and possible scaling effects may not be included.

4.2.3 Survival of Species (% Plots) Planted from Seed (after germination).

Figure 4-6 shows the survival rates of the 33 species on the two substrates in the upper plot and the magnitude and direction of this difference in the lower plot. Generally, most species had high percent survival on both substrates. Fourteen of the 33 species had 100% survival (4 of 4 plots) on <u>both</u> the soil substrate as on the gravel substrate (Figure 4-6). Notably, a few species experienced lower survival rates: *Carex lupuliformis* (#7), *Eupatorium perfoliatum* sp (#13), *Verbena hastada* (#31), and *Angelica atropurpurea* (#32). Three species survived better on the soil: *Cacalia sauveolens* (#6), *Carex frankii* (#14), and *Mentha* sp 3 (#24). Some (7) species actually survived better on the gravel

substrate compared to the soil substrate including the following species: (#7) *Carex lupuliformis* , (#10) *Chelone glabra*, (#12) *Eupatoriadelphus maculatus*, (#13) *Eupatorium perfoliatum* sp, (#28) *Scirpus pendula*, (#31) *Verbena hastada*, and (#32) *Angelica atropurpurea*. The nine species that failed to germinate on either substrate were not considered in the survival statistics.

In general, most species had high survival rates on the two substrates. Most species survived equally on both substrates, but a couple species preferred soil and a notable number of species actually survived better on the gravel substrate. Again, species must be examined on an individual basis because we cannot predict the survival tendencies of the species. The plants that survived in the first year are not guaranteed to survive equally well or demonstrate the same substrate preferences in the second year or subsequent years, because the nature of succession is unpredictable and many factors come into play. We can speculate that survival during the first year is perhaps the most difficult and critical because the plant is establishing itself and at a very vulnerable stage. We could further speculate that these seedlings would also be more sensitive to local moisture contours or standing water even less than a half inch deep because they are initially so short and their root systems may only extend a very short distance (even inches) outwards or downwards from the plant. From these speculations we could propose that once the plants become established the survival rates on both sides will be equal for all the species. In other words, while there may continue to be discrepancies in the height and density (or biomass) of the species on the two substrates, I expect the survival rate will equalize in the out years.



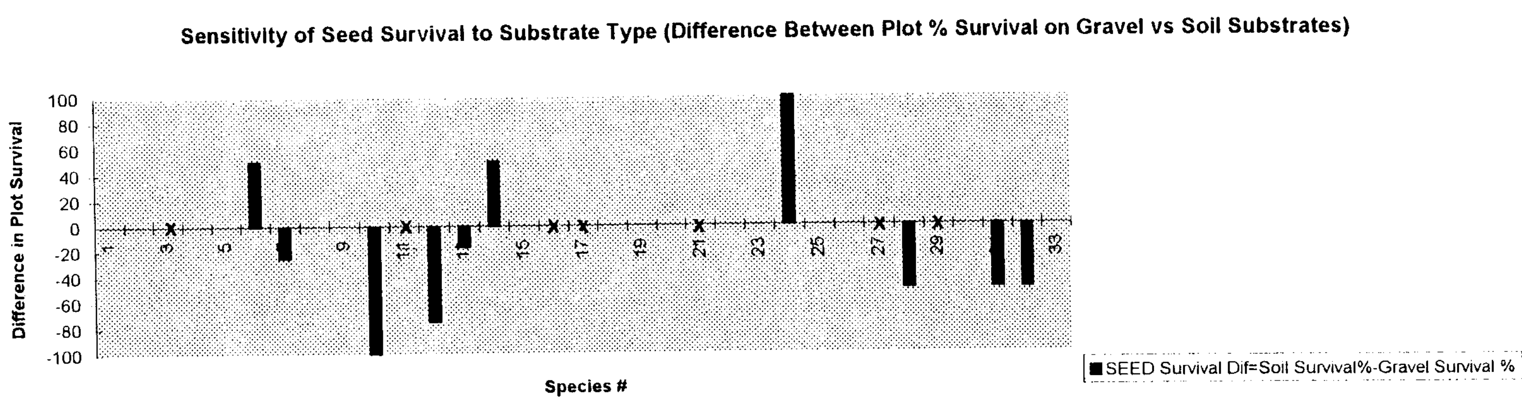
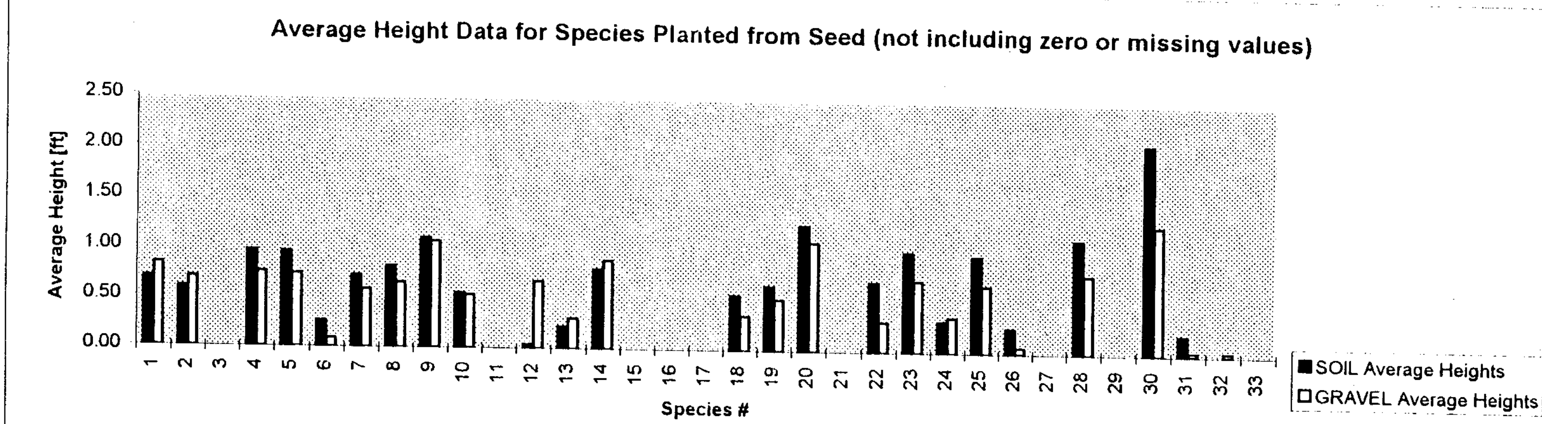


Figure 4-6 Plot Survival Rate for Species Planted From Seed

Species Key

1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

4.2.4 Average Maximum Height of Species Plots Planted From Seed (not including zero or missing values). Figure 4-7 shows the average maximum height of the species plots on the two substrates in the upper plot and the magnitude and direction of the differences between substrates in the lower plot. In general, according to the average maximum height of the species plots, species planted from seed grew better (taller) on the soil substrate than on the gravel substrate. Nine (9) species failed to grow from seed on either the soil or the gravel substrate in the first growing season, giving no indication of substrate preference for those species. Seventeen (17) out of 24 species that "germinated", grew better on the soil substrate. However, one species, (#12) *Eupatoriadelphus maculatus*, showed notably better growth on the gravel side compared to the soil side, (0.63 ft or ~7"). While a slightly better growth on gravel substrate occurred for an additional six (6) species including: (#1) *Carex hystricina*, (#2) *Mentha* sp, (#13) *Eupatorium perfoliatum* sp, (#14) *Carex Frankii*, (#24) *Mentha* 3 sp, and (#32) - *Angelica atropurpurea*. Again we cannot make a blanket statement regarding whether the plant species grow better on the soil compared to the gravel till as represented by the average maximum heights. Notably missing values and zeros are not included in the calculation of these average maximum heights, therefore germination and survival rates do not impact the values.



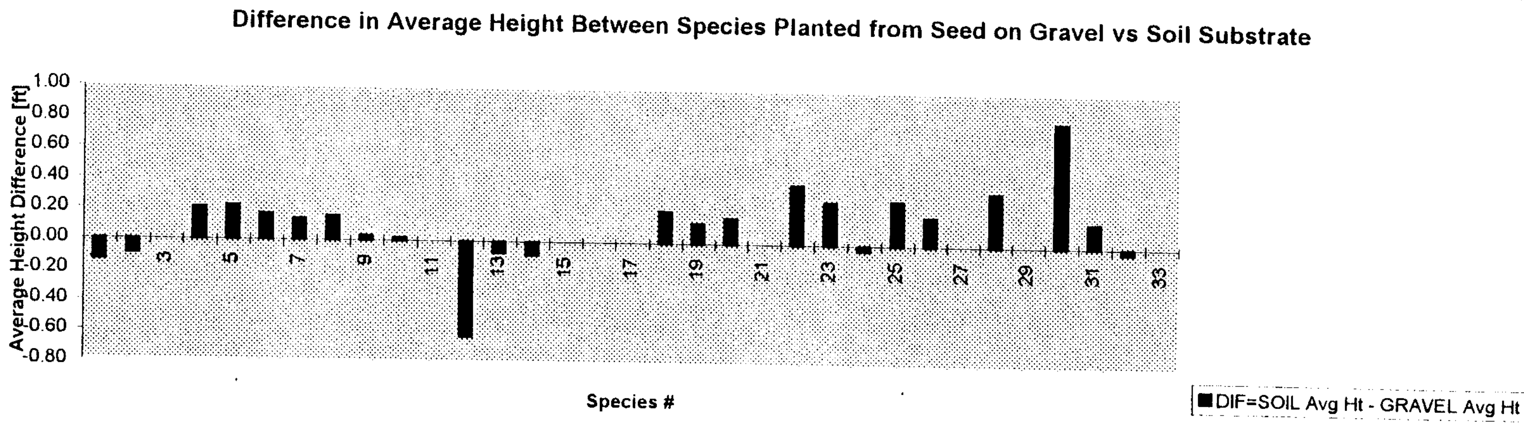


Figure 4-7 Average Maximum Plot Height Data for Species Planted From Seed

Species Key

1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

4.3 FOCUS QUESTION 3 - COMPARISON OF THE IMPACT OF PLANTING METHODS ON SPECIES SUCCESS IN TWO SUBSTRATES -- GREENHOUSE VS SEED.

4.3.1 Modified Maximum Height Data. The data from Figures 4-1 and 4-4 is displayed side by side in Figure 4-8 to give a visual comparison of the impact of planting methods on species success in the two substrates. By examining Figure 4-8 we can see whether a given species shows the same general substrate preference when it is planted from seed as when it is planted from greenhouse stock. For example, if the ordinal p-values are both positive (upward) on the plot for a given species, then that species prospers better in soil when it is planted from seed and also when it is planted from greenhouse stock. We can also determine whether the planting method impacts the sensitivity or degree of substrate preference for individual species. If the plot shows that for this given species the p-values are in the same direction but not the same magnitude, this indicates that the degree of preference for the given substrate varies depending on the planting method. Figure 4-9 presents this same data in a matrix of substrate preference and planting method.

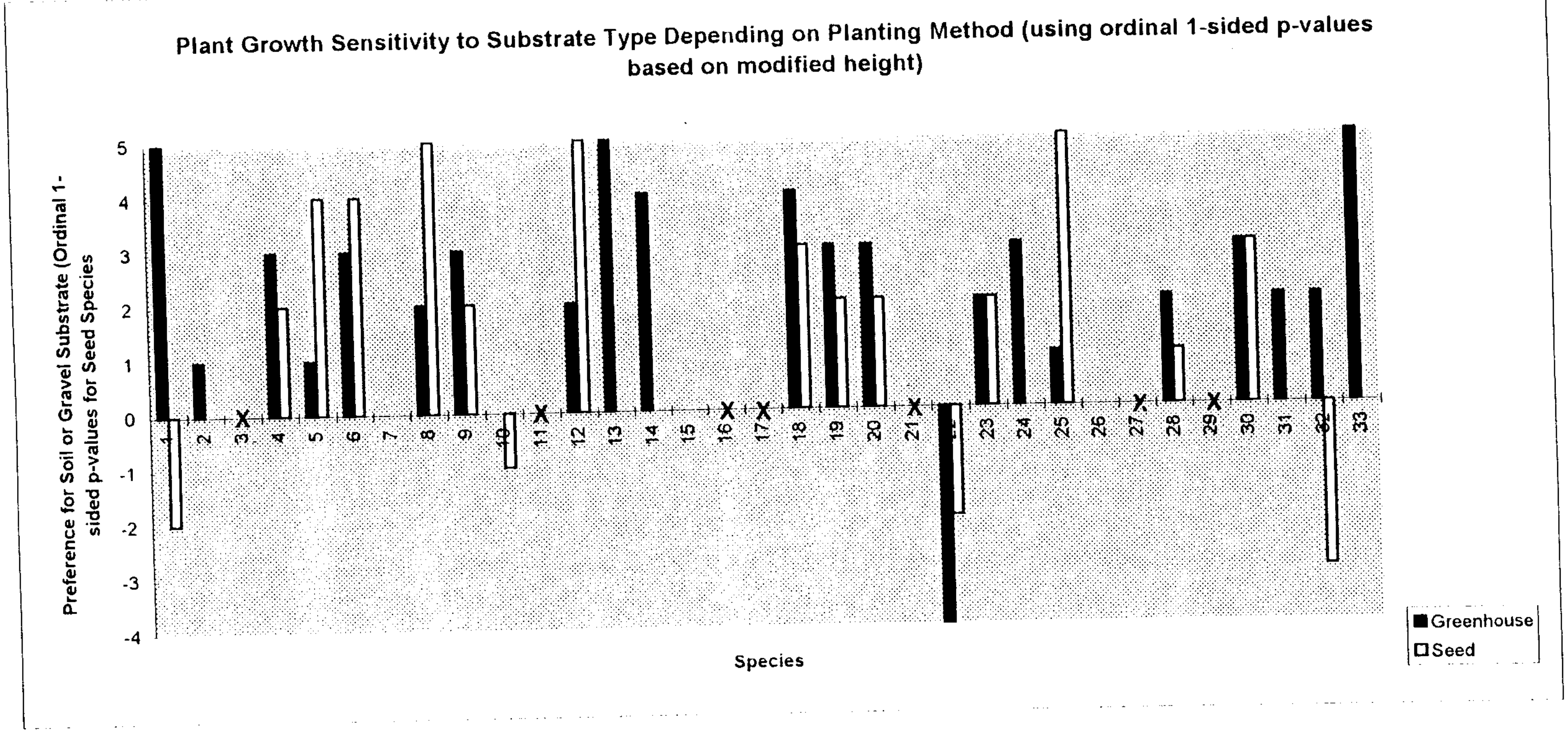


Figure 4- 8 -- Comparing the Sensitivity of Two Planting Methods to the Use of Soil or Gravel Substrate (Using 1-sided ordinal p-values)

Interpretive Key: Bar Height indicates strength of preference; (+) indicates preference for soil; and (-) a preference for gravel till

Species Key
1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

Examining Figure 4-8 we find 9 of the 33 species were equally total failures on the gravel till as on the soil given either planting method: (#3) *Pedicularis lanceolata*, (#7) *Carex lupuliformis* , (#11) *Potentilla fruticosa* , (#15) *Filipendula rubra*, (#16) *Pycnanthemum*, (#17) *Gentiana clausa*, (#21) *Lobelia cardinalis*, (#27) *Physostegia*, and (#29) *Thelypteris Thelypteroides*. These nine (9) species failed to germinate in either substrate when planted from seed and either were not planted at all from greenhouse stock or all subsequently died.

Many species preferred the soil substrate when planted with either method. Two species: (#23) *Carex prairea* and (#30) *Scirpus validus* showed the same level of preference (same ordinal p-values) for soil substrate regardless of the planting method. An additional five (5) of the 33 species showed a <u>greater</u> level of preference (higher ordinal p-value) for soil substrate when planted from <u>seed</u> rather than greenhouse stock: (#5) *Carex lurida*, (#6) *Cacalia sauveolens*, (#8) *Carex stipata*, (#12) *Eupatoriadelphus maculatus*, and (#25) *Carex cristatella*.

Six species preferred soil substrate when planted from greenhouse stock but grew equally well in both substrates when planted from seed: (#2) *Mentha* sp, (#13) *Eupatorium perfoliatum* sp, (#14)*Carex frankii*, (#24) *Mentha* sp 3, (#31)*Verbena hastada*, and (#33)*Solidago riddelii* (#33). In the case of (#33) *Solidago riddelii*, the p-value is attributed to the fact the species failed to grow from seed in either of the substrates, thus the species obviously prefers the greenhouse planting method in the first growing season.

Perhaps most notable are the species which exhibited a preference for gravel till for one or both of the planting methods according to the ordinal p-value data. Species (#1) *Carex hystricina,* and (#32) *Angelica atropurpurea* preferred soil substrate when planted from greenhouse stock, but prospered better in gravel till when planted from seed. *Chelone glabra* (#10) showed no substrate preference when planted from greenhouse stock but prospered better in gravel till when planted from seed. Lastly, (#22) *Mentha* sp 2 preferred gravel till when planted from greenhouse stock as well as when it was planted from seed.

In general the p-value data showed many species preferred soil to varying degrees regardless of planting method, however some species preferred gravel when planted from seed only, some species grew equally on the two substrates only when planted from seed, and one species preferred gravel with either planting method. This information is important to a planner in helping him decide which species and which planting methods to employ on a given substrate to obtain the best overall results. Because of the way it is calculated, the p-value data factors in germination, survival, and plant growth (height) to give an overall view of species "success".

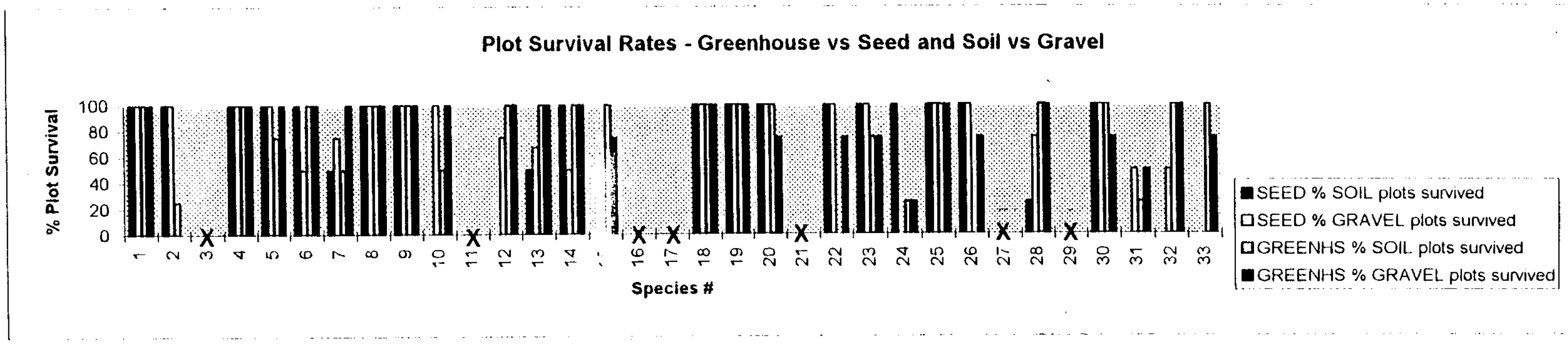
Fig 4-9 – Matrix of Substrate Preference Based on Modified Height (1-sided p-Values)			
		Planting Method:	
Species #	Species	Greenhouse	Seed
1	*Carex hystricina* (Porcupine Sedge)	SOIL	GRAVEL
2	*Mentha* sp (Mint)	No difference	No difference
3	*Pedicularis lanceolata* (Swamp Loosewort)	NA	NA
4	*Carex stricta* (Tussock Sedge)	SOIL	SOIL
5	*Carex lurida* (Shallow Sedge)	SOIL	SOIL
6	*Cacalia sauveola* (Sweet-scented Indian Plantain)	SOIL	SOIL
7	*Carex lupuliformis* (False Hop Sedge)	No difference	No difference
8	*Carex stipata*	SOIL	SOIL
9	*Carex vulpinoidea* (Fox Sedge)	SOIL	SOIL
10	*Chelone glabra* (Turtlehead)	GRAVEL	GRAVEL
11	*Potentilla fruticosa* (Shrubby Cinquefoil)	NA	NA
12	*Eupatoriadelphus maculatus* (Joe Pye)	SOIL	SOIL
13	*Eupatorium perfoliatum* (Boneset)	GRAVEL	No difference
14	*Carex Frankii* (Frank's Sedge)	GRAVEL	No difference
15	*Filipendula rubra* (Queen of the Prairie)	NA	NA
16	*Pycnanthemum*	NA	NA
17	*Gentiana clausa* (Closed Gentain)	NA	NA
18	*Asclepias incarnata* (Swamp milkweed)	SOIL	SOIL
19	*Juncus articulatus* (Jointed Rush)	SOIL	SOIL
20	*Juncus torreyi* (Torrey's Rush)	SOIL	SOIL
21	*Lobelia Cardinalis* (Cardinal Flower)	NA	NA
22	*Mentha* sp 2 (Mint)	GRAVEL	GRAVEL
23	*Carex prairea* (Prairie Sedge)	SOIL	SOIL
24	*Mentha* sp 3 (Mint)	SOIL	No difference
25	*Carex cristatella* (Crested Sedge)	SOIL	SOIL
26	*Sanguisorba canadensis* (Canadian Goldenrod)	No difference	No difference
27	*Phytosegia purpurea* (Purple Dragon-head)	NA	NA
28	*Scirpus pendula* (Drooping Bulrush)	SOIL	SOIL
29	*Thelypteris thelypteroides* (Marsh fern spores)	NA	NA
30	*Scirpus validus* (Soft-stem Bulrush)	SOIL	SOIL
31	*Verbena hastada* (Blue Vervain)	SOIL	No difference
32	*Angelica atropurpurea* (Great Angelica)	SOIL	GRAVEL
33	*Solidago riddelii* (Riddel's Goldenrod)	SOIL	No difference
Interpretation Key:			
	SOIL = Species grew better on soil substrate (per ordinal 1-sided p-values)		
	GRAVEL = Species grew better on gravel substrate		
	No difference = Species grew equally well on gravel and soil substrates		

Figure 4-9 Substrate Preference Based on One-sided p-Values of Modified Height Comparisons

4.3.2 Comparison of Plot Survival on Soil and Gravel Substrates when Planted from Seed and from Greenhouse Grown Plants

Figure 4-10 shows the individual plot survival rates in the upper plot and the difference between survival on the two substrates for each of the planting methods in the lower plot. Figure 4-10 shows that most species enjoyed high survival rates (75% to 100%) with both planting methods but some (7) species failed to grow with either method. From Figure 4-10 we find as we would expect that many species have lower survival rates when planted from seed compared to when planted from greenhouse grown stock. However, we also find that some (5 sp) have higher survival rates when planted from seed.

The impact planting method has on the sensitivity to substrate type can be seen most dramatically in the case of species (#10) *Chelone glabra,* (#12) *Eupatoriadelphus maculatus*, (#22) *Mentha* sp 2, (#24) *Mentha* sp 3, and (#26) *Carex cristatella.* While species (#10) *Chelone glabra* survived better on the gravel side than the soil side in the case of both planting methods, the difference in survival rates was more dramatic in the case of greenhouse stock. Species (#12) *Eupatoriadelphus maculatus* survived much better in gravel when planted from greenhouse stock but survived equally well on the two substrates when planted from seed. Species (#22) *Mentha* sp 2 and (#26) *Sanguisorba canadensis* exhibited the opposite trend, by surviving better in gravel when planted from seed but survived equally well in the two substrates when planted from greenhouse stock. Lastly species (#24) *Mentha* sp 3 survived only in the soil when planted from seed but survived equally (but poorly 25%) on both substrates when planted from greenhouse stock.



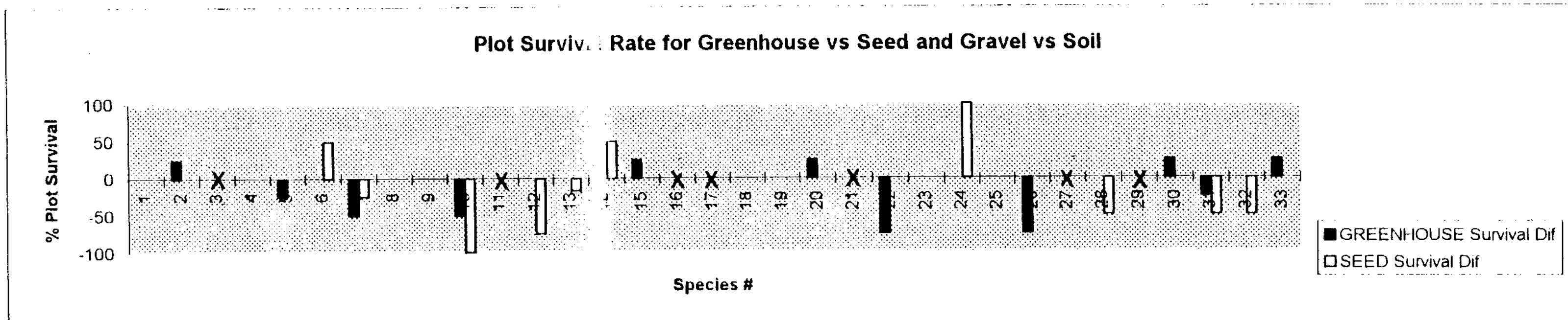


Figure 4-10 -- Comparison of Species Survival for Tw , Planting Methods and Two Substrates (Based on Fig 4-2 and Fig 4-6)

<u>Species Key</u>
1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia suaveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadel..hus maculatus* (Joe Pye)
13 *Eupatorium ,erfoliatum* (Boneset)
14 *Carex franki.* (Frank's Sedge)
15 *Filipendula ..bra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

The survival information is important to the wetland restoration planner, because he may decide to plant more of a particular species to compensate for low survival rates, or he may choose a particular planting method to ensure greater survival rates for that species. First year survival is critical. If the species have high failure (death) rates in the first year, it may be necessary to replant which would be time-consuming, expensive, and delay the establishment of vegetative coverage.

4.4 FOCUS QUESTION 4 - GROWTH RATES OF SPECIES IN PLUGS TRANSPLANTED FROM NATURAL WETLANDS. The growth rates the plug species on the two substrates in tabular form in Figures 4-11 and in histogram form in Figure 4-12. The growth rates (slopes) were calculated for the species growing in the plugs for which we had enough data points.

Negative slopes or growth rates may be due a flaw in the measuring methodology. Plants (like *Carex* sp) were measured at their tallest new growth height and then later after more growth the plant is weighed down by its own weight and "droops" over. This phenomena would lead to the data mistakenly indicating the plant is "shrinking" although the plant is actually continuing to grow. This would be an error in the measuring method rather than an error in the execution of the method. Some Plug species such as the Iris also drooped over from its height and was measured at its maximum drooped height rather than straightened up and measured in total stem length. Because of such methodology errors, species with negative slopes, negative growth rates, were ignored.

Considering only the species exhibiting positive growth rates for both the gravel and soil substrates, we find three of seven species exhibited roughly equivalent growth rates (in/day)in both of the substrates: (#20) *Juncus torreyi,* (#26) *Sanguisorba canadensis*, and (#35) *Carex* sp. The other four species had greater growth rates on the soil substrate compared to the gravel till including: (#4) *Carex stricta,* (#14) *Carex frankii,* (#2) *Mentha* sp, and (#37) *Acorus calamus* (Sweetflag).

We cannot directly compare the growth of species originating from transplants taken from natural wetlands to the success or growth of species planted from seed or from greenhouse grown stock, however we can make limited conclusions. Both the soil and the gravel substrates did support the growth of species from natural plugs. This is significant because in many cases plants are rescued from wetlands which are planned for destruction and transplanted into a wetland restoration site. The species from natural plugs were in a later portion of the growing curve, being more mature plants, compared to specimens planted from seed or greenhouse stock. The plug specimens therefore exhibited less growth in height as would be expected. The specimens should be observed in future years to subjectively determine if they will propagate or spread outward and become more dense at equal rates on the soil and the gravel substrates.

Many experts assert that the best source for planting or stocking materials is nearby natural wetland since that stock will be adapted to the climatic and edaphic conditions of the area (Hammer ,1992; Mitsch and Gosselink, 1993; van der Valk, 1989). Because the introduction species that do no occur in natural wetlands near the restoration or creation site often results in planting failure and worse yet may introduce an exotic pest species, transplanting vegetation from the wetland site being destroyed to the created wetland is recommended when possible (Lowry, 1990:275; Munro, 1991:85). Transplanting in local plants, or whole sods, may be more expensive than seeding or using nursery-raised plants but has the advantages of furnishing large, well established, and usually genetically diverse stock. Munro (1991) Jarman (1991), however, found nursery-

grown native shrubs and saplings generally survived better than those transplanted from the lost wetlands.

Species #	Plug Species	Growth Rate on GRAVEL [in/day]	Growth Rate on SOIL [in/day]	DIFFERENCE in Growth Rates (SOIL-GRAVEL) [in/day]	Species Grows Faster on This Substrate (GRAVEL or SOIL)
4	Carex Stricta (Tussock Sedge)	0.00037	0.00384	0.00347	Soil
13	Eupatorium perfoliatum (Boneset)	0.00533	NA	NA	NA
14	Carex frankii (Frank's Sedge)	0.00128	0.01365	0.01237	Soil
15	Filipendula rubra (Queen of the Prairie)	NA	NA	NA	NA
19	Juncus articulatus (Jointed Rush)	NA	NA	NA	NA
20	Juncus torreyi (Torrey's Rush)	0.01048	0.01144	0.00096	Soil
25	Carex Cristatella (Crested Sedge)	NA	0.05611	NA	NA
26	Sanguisorba Canadensis (Canada Burnet)	0.04702	0.04657	-0.00045	Gravel (slightly)
28	Scirpus pendulus (Drooping Bulrush)	NA	0.00147	NA	NA
2	Mentha sp (Mint)	0.00360	0.00709	0.00349	Soil
35	Carex sp (Sedge)	0.00606	0.00664	0.00058	Soil
37	Acorus Calamus (Sweetflag)	0.00036	0.00899	0.00863	Soil
40	Iris sp (Iris)	NA	0.00601	NA	Soil

<u>Interpretation Key:</u> NA indicates Not Applicable or Bad Data due to an error in the measuring methodology. The data showed a Negative growth rate for these species, but the plant was not actually "shrinking" or getting shorter.

Figure 4-11 Plug Specimens Growth Curve Slopes (Rate = [in/day]) Comparison Between Soil Types

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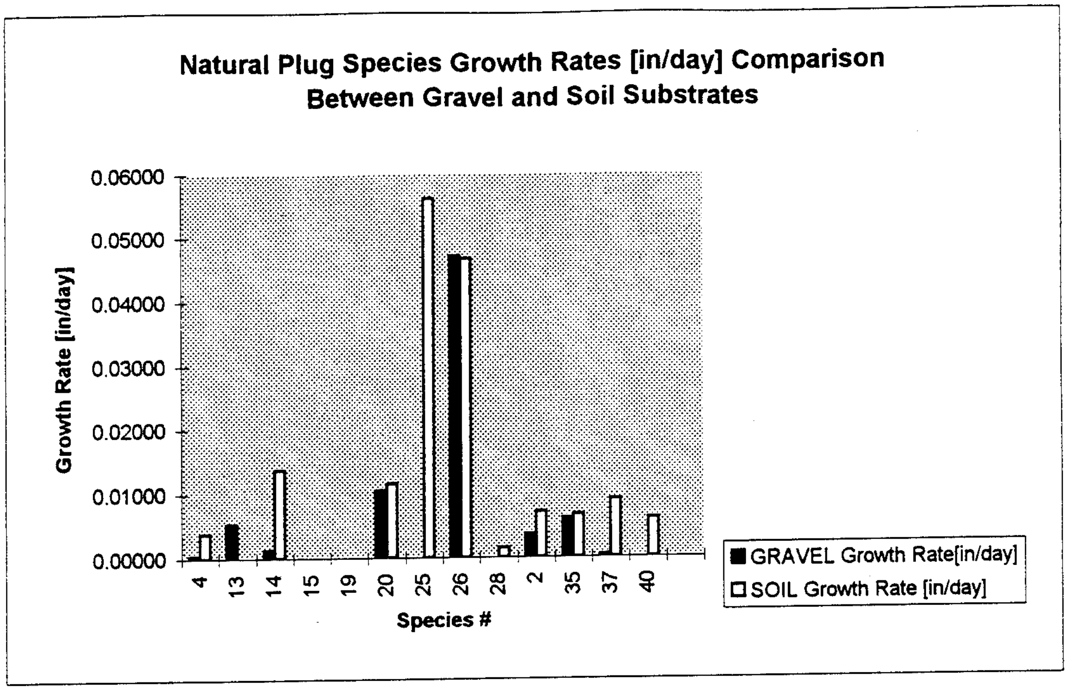


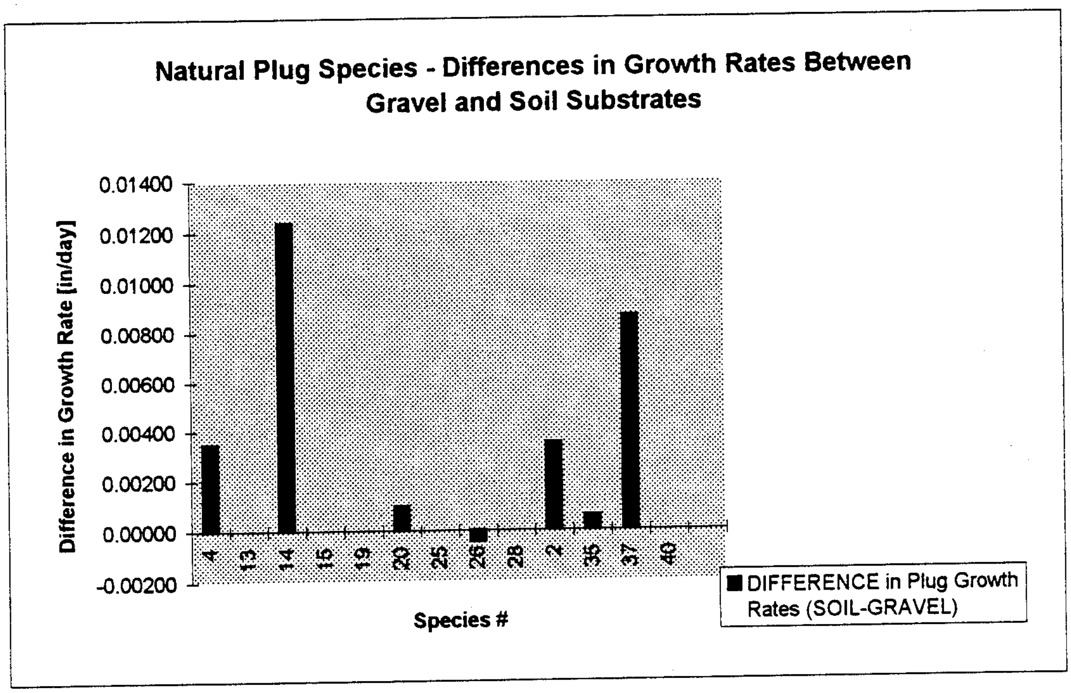


Figure 4-12 Comparison of Growth Rates for Plug Species on Soil versus Gravel Substrate (bar plot)

Species Key
1 *Carex hystricina* (Porcupine Sedge)
2 *Mentha sp* (Mint)
3 *Pedicularis lanceolata* (Swamp Loosewort)
4 *Carex stricta* (Tussock Sedge)
5 *Carex lurida* (Shallow Sedge)
6 *Cacalia sauveolens* (Sweet-scented IndianPlantain)
7 *Carex lupuliformis* (False Hop Sedge)
8 *Carex stipata*
9 *Carex vulpinoidea* (Fox Sedge)
10 *Chelone glabra* (Turtlehead)
11 *Potentilla fruticosa* (Shrubby Cinquefoil)
12 *Eupatoriadelphus maculatus* (Joe Pye)
13 *Eupatorium perfoliatum* (Boneset)
14 *Carex frankii* (Frank's Sedge)
15 *Filipendula rubra* (Queen of the Prairie)
16 *Pycnanthemum* (Mountain Mint)
17 *Gentiana clausa* (Closed Gentain)
18 *Asclepias incarnata* (Swamp Milkweed)
19 *Juncus articulatus* (Jointed Rush)
20 *Juncus torreyi* (Torrey's Rush)
21 *Lobelia cardinalis* (Cardinal Flower)
22 *Mentha* sp 2 (Mint 2)
23 *Carex prairea* (Prairie Sedge)
24 *Mentha* sp 3 (Mint 3)
25 *Carex cristatella* (Crested Sedge)
26 *Sanguisorba canadensis* (Canada Burnet)
27 *Physostegia purpurea* (Purple Dragon-head)
28 *Scirpus pendula* (Drooping Bulrush)
29 *Thelypteris thelypteroides* (Marsh Fern)
30 *Scirpus validus* (Soft-stem Bulrush)
31 *Verbena hastada* (Blue Vervain)
32 *Angelica atropurpurea* (Great Angelica)
33 *Solidago riddellii* (Riddell's Goldenrod)

4.5 BIOMASS DATA RESULTS

4.5.1 FOCUS QUESTION 5 - DRY WEIGHT/SAMPLE AREA OF BIOMASS.

Three biomass samples from each of the four plots on each of the two sides were collected and processed for a total of 24 samples. The average dry weight/sample area, phosphate content/sample area, and percent organic content of the four plots on each substrate are presented in Table 4-2. The sample area was 15 cm X 15 cm or 225 cm^2 = 0.0225 m^2. Notably, the dry weight of the biomass samples taken on the soil side were on average consistently greater (Table 4-2) than the gravel side.

Table 4-1 Average of Plots 1-4 Biomass Values on the Two Substrates

	SOIL substrate	GRAVEL substrate
Dry Weight [g/m^2]	334.70	203.11
PO_4^{-3} [mg PO_4^{-3} / g dry wt of biomass]	31.739	20.615
% Organic Content	91.082*	89.273

(* = does not include one outlier, sample #12 in plot #4)

There is some variation within plots and between plots the complete dataset in Appendix D, and in the scatterplots in Figure 4-13, and the bar graphs of the plot averages in Figure 4-14. When looking at Figure 4-13, samples 1-3 correspond to plot #1, samples 4-6 to plot #2, and so on. The scatterplot we find three notable exceptions to the overall

trend of dry weight being greater on the soil side: sample #2 (of plot #1), sample #6 (of plot #2), and sample #12 (of plot #4). These exceptions and the variations within plots as found on the scatterplot (Fig 4-13) and the variation between plots as illustrated in Figure 4-14 corresponded to higher water levels. Areas of standing water appears to have favored the growth of emergent species like *Alisma subcordatum* and may have inhibited the sedge population growth, and thus in turn reducing the dry weight biomass in these areas. For example, a majority of the seed mixture area in plot #2 on the gravel side had a 1/4" to 1/2" of standing water, contributing to the low average and individual dry weights for this area as seen in Figures 4-13 and Figures 4-14.

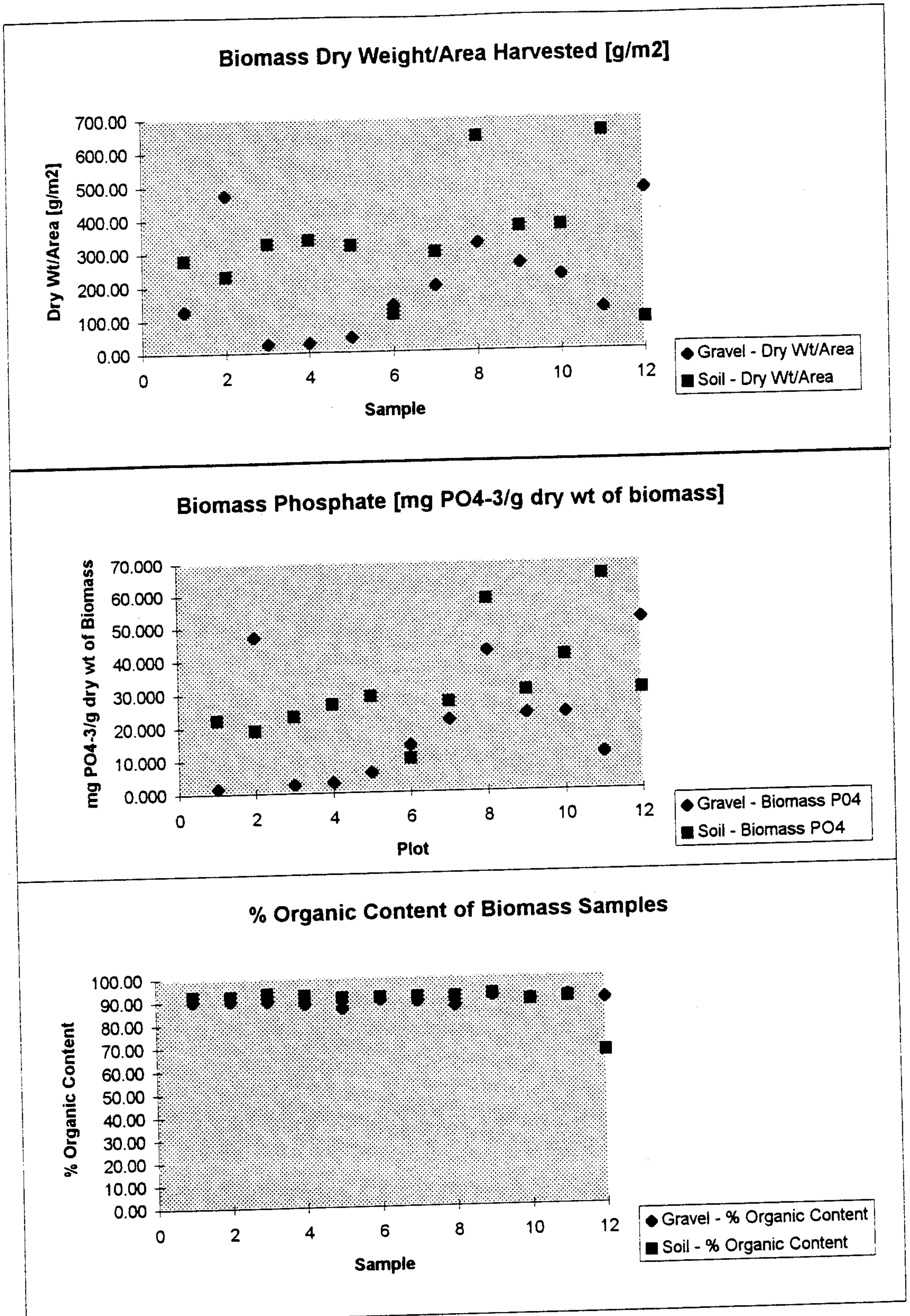


Figure 4-13 Scatter Plot of 12 Samples from Each Soil Substrate - Dry Wt/Sample Area, Organic Content, and Phosphate Content of Biomass Samples

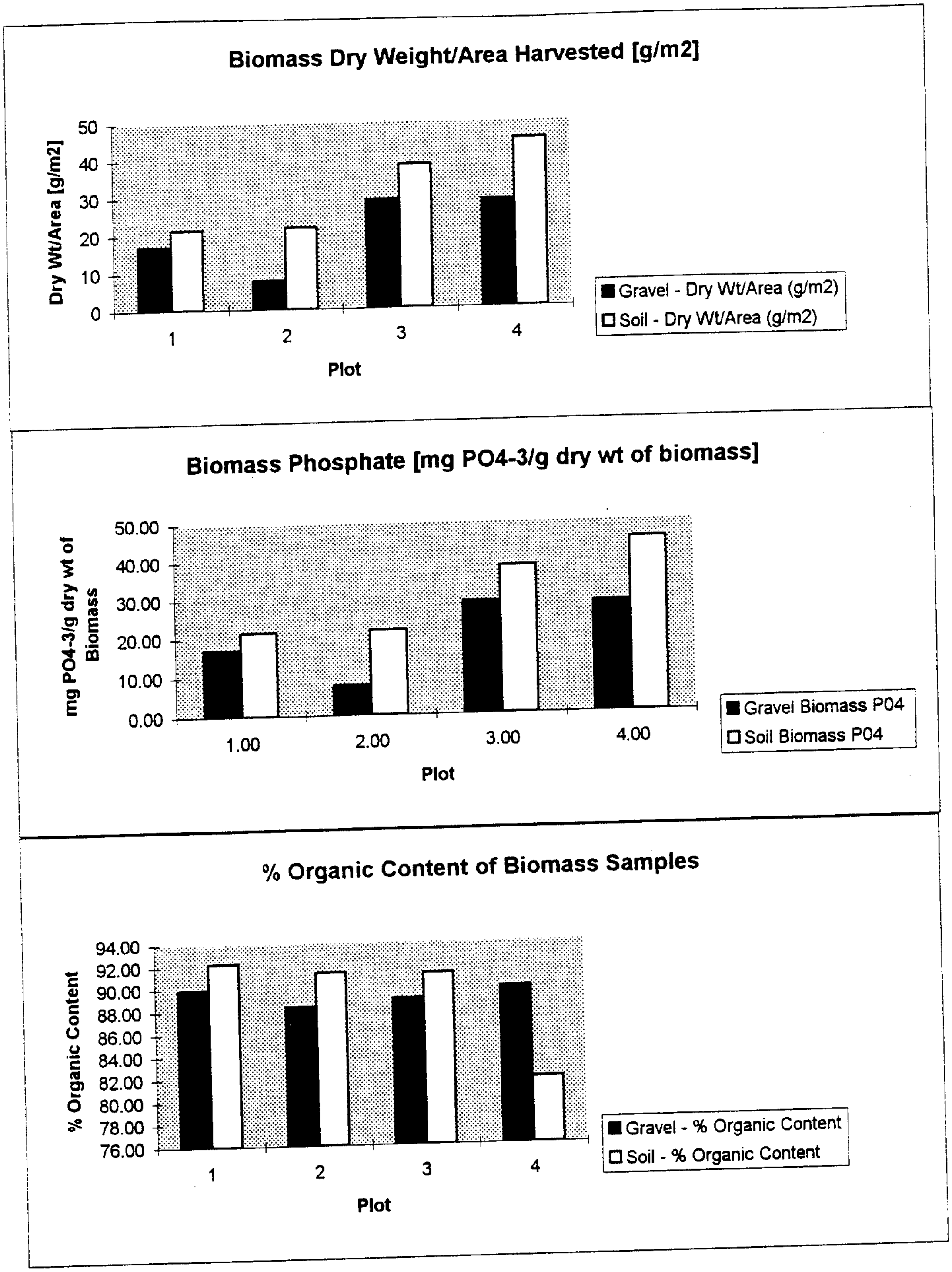


Figure 4-14 Bar graph of Plot Averages on Two Substrates - Dry Wt/Sample Area, Organic Content, and Phosphate Content of Biomass Samples

4.5.2 FOCUS QUESTION 6 - ORGANIC CONTENT OF BIOMASS.

Examining the raw data in Appendix D and the Figure 4-13 scatterplot we see that the biomass samples taken from the soil substrate generally had a slightly higher organic content, with the exception of sample #12 in plot #4 on the soil substrate, which brought down the plot average as seen in Figure 4-14. This outlier, 66.34% organic content, was far outside the range, 89.11% to 92.93%, of the other 11 samples. The outlier corresponded to an area with standing water, a "puddle". When this outlier is not included in the averaging, the organic content on the soil side was an average of 91.082% compared to an average 89.273% on the gravel till. Not including the outlier, there was very little variance in the organic content of the biomass.

4.5.3 FOCUS QUESTION 7 - PHOSPHATE CONTENT OF BIOMASS.

Table 4-2 showed that on average the biomass samples taken from the soil side had higher phosphate content than those taken from the gravel side. The scatter plot (Figure 4-13) showed the biomass phosphate levels had a considerable variance on the gravel substrate as well as on the soil substrate. Three samples were taken from each of the four plots on both substrates, for a total of twelve measurements on each substrate. The biomass phosphate levels on the gravel substrate varied from a low of 1.560 [mg PO_4^{-3}/g dry wt of biomass] for one sample from plot #1 to a high of 51.670 [mg PO_4^{-3}/g dry wt of biomass] for a sample from plot #4. Similarly, the biomass phosphate levels on the soil substrate varied considerably from a low of 9.960 [mg PO_4^{-3}/g dry wt of biomass] for a sample from plot #2 to a high of 65.380 [mg PO_4^{-3}/g dry wt of biomass] for a sample from plot #4.

The levels also varied within the three samples taken per plot on a given side, not just between plots. For example, on the gravel side, the three biomass phosphate levels in plot #1 were 1.560, 2.570, and 47.070[mg PO_4^{-3}/g dry wt of biomass]; while on the soil side, the levels in plot #4 were 30.070, 40.560, and 65.380[mg PO_4^{-3}/g dry wt of biomass].

Even when the averages of the three samples per plot were calculated and these averages subsequently compared in a histogram (Fig 4-14), the significant variance were still apparent. The average biomass phosphate levels on the gravel substrate varied from 29.020 to 7.657 [mg PO_4^{-3}/g dry wt of biomass], while the average levels on the soil substrate ranged from 21.427 to 45.337 [mg PO_4^{-3}/g dry wt of biomass]. Figure 4-14 (histogram) shows the average biomass phosphate levels on the soil substrate for each of the four plots consistently exceeded the sample levels taken from the gravel substrate, although magnitude [mg PO_4^{-3}/g dry wt of biomass] of this difference varied: 4.360 for plot #1, 14.140 for plot #2, 9.323 for plot #3, 16.620 for plot #4. In the case, of sample #3 from plot #1 on the gravel side, and samples #1 and #2 from plot #2 on the gravel side, the sample areas lied near or in a depression ("puddle") with standing water roughly 1 cm deep. Little vegetation grew in these "puddle" regions contributing to the low wet sample weight, subsequent low dry weight, and low Biomass PO_4^{-3}.

Biomass phosphate levels are an indication of how well the plants are taking up the available phosphate. Since phosphate is an important nutrient for wetland species, the higher phosphate levels may also indicate "healthier" more robust plants. The water chemistry data results as discussed in section 4.6 found that both sides were receiving similar supplies of phosphate from the water. The discrepancy in phosphate levels

therefore is an indication that the plants on the soil side are more effectively taking up and processing the available phosphate. Microbes are often associated with the roots of certain plant species and aid in the uptake of nutrients such as phosphate. It is possible these microbes are present in the organic soil but have not had time to become established in the gravel till. As discussed in chapter 2, many researchers have suggested that large or tiny (inoculant) amounts of wetland soils be used in restoration sites in order to supply these useful microbes. The microbes will probably become established because of the close proximity of the gravel side to the soil side and of the site to local natural wetlands. Thus, I would expect this discrepancy between phosphate levels on the two substrates to diminish with time.

4.5.4 Biomass Observations. The seed mixture was dominated, in this first season, by annuals such as *Alisma subcordatum* and *Cyperus flavescens*. Numerous other seedlings (probably perennials) have begun to show growth now at the end of the season, suggesting that a period of succession will proceed in the following years.

4.6 FOCUS QUESTION 8 & 9 - WATER CHEMISTRY.

The chemistry of the water at the influent, the effluent, and throughout the site exhibited a similarity to fens seen regionally, throughout the U.S. and worldwide (Table 4-7). This is significant because it verifies the establishment of fen water chemistry conditions, attesting to the fact we adequately replicated the water chemistry conditions present in a natural fen or required for a restored fen. It is notable that the range of water chemistry conditions found in natural wetlands are quite large. It appears that one critical

water chemistry parameter for a fen is the circumneutral (5-9) pH even though that is a broad range (10^4) of hydrogen ion concentration. It is likely that water flow is the key to maintaining the constant water chemistry seen. Nutrients are not exhausted and wastes of metabolism are constantly swept away from the root zone. This special condition is common to no wetland system other than fens.

Table 4-2 Experimental Water Chemistry Compared to Values from the Literature for Fens.

	<u>**Range: (scale is arbitrary)**</u>
pH	7.5 **5--------------9**
Phosphate [mg/l]	0---0.08 **0---------0.27**
Sulfate [mg/l]	35---75 **0---------------------1305** **(most below 150)**
Nitrate [mg/l]	0----1.496 **0--------------18.0**
Iron [mg/l]	0---0.20 **0-----------598**
Alkalinity [mg/l]	30---59 **0.3--------------598**
Ammonium ion [mg/l]	0.26---0.65 **0------------------0.9**
Ca^{2+} Hardness [mg/l]	0.26---0.65 **0------------------0.9**
Mg^{2+} Hardness [mg/l]	0---204 **0------------306**

***Note: The values from the literature for fens are in BOLD type and the scale is arbitrary.**

Table 4-3 Summary Comparison of Water Chemistry in the Upper vs Lower Depths and in the Soil vs Gravel Substrates

Water Chemistry Parameter [mg/l] (except pH)	Soil Lower	Gravel Lower	Dif Lower= Soil-Gravel	Soil Upper	Gravel Upper	Dif Upper = Soil-Gravel	Soil Dif = Upper-Lower	Gravel Dif = Upper-Lower
pH	7.5	7.5	0	7.5	7.5	0	0	0
Phosphate	0	0	0	0.01	0.01	0	0.01	0.01
Sulfate	44.43	48.4	-3.97	47.625	53.625	-6.000	3.195	5.225
Nitrate	0.151	0.132	0.0189	0.220	0.446	-0.226	0.069	0.314
Iron	0.071	0.065	0.006	0.064	0.028	0.036	-0.007	-0.037
Alkalinity	**40.1**	**46**	**-5.9**	**37.875**	**43.625**	**-5.75**	**-2.225**	**-2.375**
Ammonium Ion	0.343	0.370	-0.0275	0.179	0.203	-0.024	-0.164	-0.167
Total Hardness	189.4	212.5	-23.1	193.375	231.625	-38.25	3.975	19.125
Ca^{2+} Hardness	**106.9**	**144.5**	**-37.6**	**74.375**	**125.375**	**-51.000**	**-32.53**	**-19.125**
Mg^{2+} Hardness	96.3	68	28.3	119	106.25	12.75	22.7	38.25

*** Note the values for Alkalinity and Ca^{2+} Hardness are in BOLD type to highlight the fact they vary notably between the samples from the soil and the gravel substrates**

The complete water chemistry data set is compiled in Appendix I. The averages for the Upper Substrate Level (0-6" below the surface) in the main plant root zone were then compiled and displayed in Appendix J, while the averages for the Lower Substrate Level (6-12" below the surface) below the main plant root zone were displayed in Appendix K. Table 4-8 provides a summary of the water chemistry values in the upper and lower substrate levels on the soil and the gravel till substrates. From Table 4-8 we see that there is little difference between the water chemistry from the plant root zone (upper 0-6" below the surface) and the layer underlying the root zone (lower 6-12" below the surface).

There is little difference between the water chemistry on the soil and gravel sides with the exception of lower alkalinity and Ca^{+2} hardness levels on the soil side compared to the gravel side. Alkalinity and Ca^{+2} are really synonymous (but with different units). The higher levels on the gravel substrate can most likely be attributed to fact that the gravel is a calcareous substrate (high in calcium) and the water is picking up dissolved Ca^{+2} from the gravel substrate itself. The pH did not vary in either substrate much (variations were below the detectable limits of the litmus paper) and this indicates a well-buffered system. Non-conservative nutrients such as nitrate and phosphate were quite low in both substrates indicating that plants were able to sequester them as rapidly as they were supplied.

In late October it was noted that calcium carbonate deposits (marl) were forming on the gravel side, but not in the soil. This probably reflected an equilibrium chemistry which slightly favors the precipitate in the gravel. Some of the marl was formed by deposits on the aquatic alga *Chara* sp which did not appear to grow as well on the soil where less water puddling was evident.

Although the chemistry varied from plot to plot and with sample depth it appears that the flow of water maintained a relatively constant chemistry around the roots of the plants (during the growing season). This indicates that there is minimal chemical buildup or change in water chemistry that can be attributed to the vegetation as can occur in other types of wetlands when there is stagnant or slow moving waterflow. In our site and in fens in general, the system is flow dominated. In other words, the amount and rate of water flowing through the system is great enough that it flushes out any chemical buildups. The water chemistry therefore appears to be dominated by the chemistry of the water supply, the deep artesian aquifer. Since the aquifer is very large, its water chemistry can be considered constant for our purposes. The evidence presented shows that this project has established a fen with almost constant water chemical parameters and nutrient levels. This would be important and desirable to a wetland restoration planner, because it means that the fen is quite stable with respect to water chemistry and would not require additional management to continually adjust the water chemistry and nutrient levels. This saves manpower and money and helps ensure the establishment of a "successful", self-sustaining fen.

4.7 SOIL MOISTURE AND STANDING WATER CONTOUR DATA.

Standing water that pooled at various locations at the surface favored the emergent species like *Alisma subcordatum* and may have inhibited the sedge population growth. The growth of filamentous green algae midsummer and fall in the pools of standing water may have also competed for nutrients with the plants and thereby reduced overall production in the gravel. Very dry areas on the gravel side in early spring also corresponded to low plant growth, germination, and survival.

The soil side of the experiment did not develop as many pools of standing water as the gravel side, partially due to the slightly lower elevation of the gravel side. The gravel also became compacted, possibly reducing its permeability. Water flowing along the surface was dammed and backed up by the boardwalk in several areas, because the water could not flow under the boards as easily on the gravel side as it could in the soil. This condition was remedied in November 1995.

A few hydrological design changes which would result in more even water flow and distribution within the site would be recommended in the construction of additional fen research sites. The construction of the water supply system was adequate, but the longitudinal layout of the screened pipe seemed to favor local foci of seepage. Future designs should incorporate a manifold with screened supply pipes that are perpendicular to the designed water flowpath (Figure 4-15). Future designs should incorporated a greater slope of the ground surface and the elevation of the boardwalk on the gravel to prevent pooling of water.

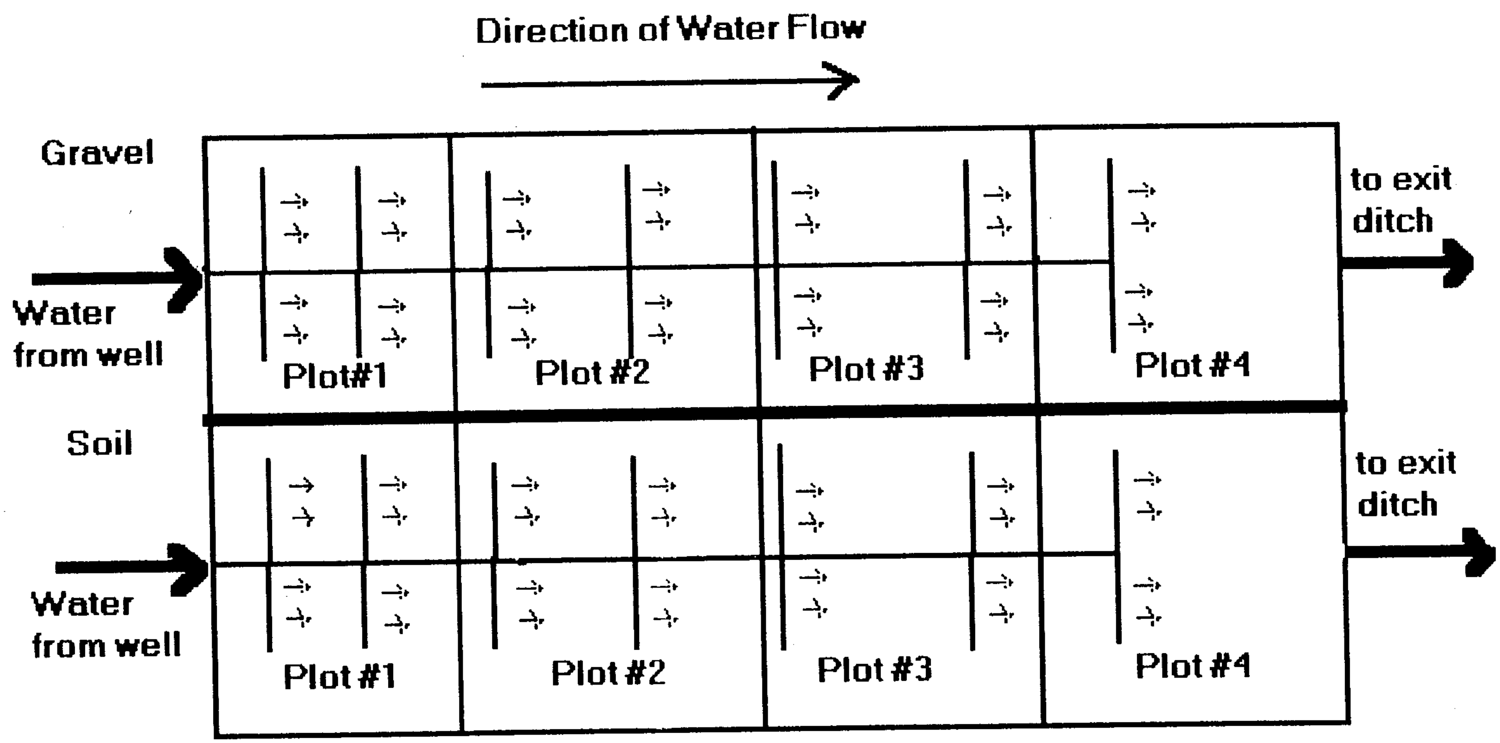


Figure 4-15 - Proposed Future Water Supply System

4.8 ADDITIONAL OBSERVATIONS AND QUALITATIVE OBSERVATIONS.

4.8.1 Accidental Application of Fine Layer of Soil to the Gravel Till. In the first week of May a heavy rain of hydric soil from the side walls down onto the seeded area (individual species) of plot #1 of the site, depositing a ~1/8" to 1/4" layer of hydric soil over the gravel (Figure 4-16). The following week the soil was scooped away, leaving only a small residual, but subsequent growth of the plants showed greater height and density in the exact pattern as formed by the former sediment deposit (Figure 4-17). This event indicates plant species may grow and prosper as well on a substrate of gravel with a small amount of soil as on a substrate of 6" of soil. This could be due to the presence of microbes such as nitrogen fixers or mycorrhizae in the hydric soil which increase phosphate activity. A controlled experiment on a constructed site similar to ours could be conducted to investigate these preliminary findings.

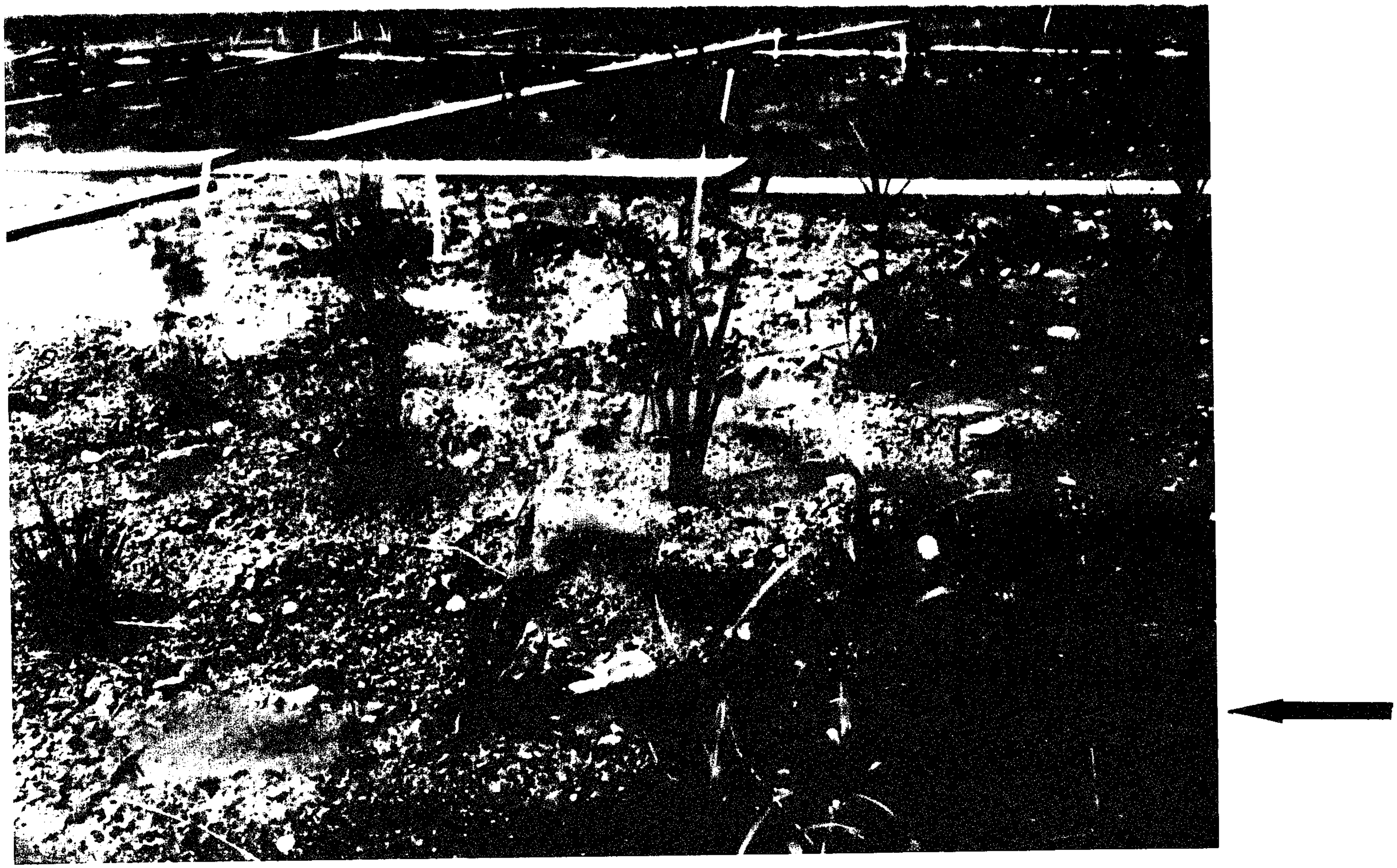


Figure 4-16 PHOTO -- Hydric Soil Deposited by Erosion from Heavy Rain (May 1995) onto Seeded Area of Plot #1 on Gravel Substrate

Figure 4-17 PHOTO -- Increased Growth in the Seeded Area of Plot #1 of Gravel Substrate Compared to that in Other Plots on the Gravel

4.8.2 Straw Added to the Seeded Areas on the Gravel Substrate. Drying and cracking at the surface was observed on the gravel substrate just after planting. Although it was receiving a comparable water flow the capillary action on the gravel till was not as strong as it was on the soil substrate because of the larger particle and pore sizes associated with the gravel. Thus, the water was not being brought to the surface as fast as it was removed by evaporation and drying and cracking occurred. Straw was spread lightly over the seeded areas of gravel used to shade seeds and seedlings and prevent rapid evaporation on the gravel till. The straw seemed to enhance the water retention ability of the till and the drying and cracking was notably reduced. Straw would be recommended if gravel till is being used, however, it would not be advised if soil was used as an amendment to the gravel till.

4.8.3 Seedbank Growth. Very little seedbank growth appeared on the gravel till relative to the robust development of the seedbank on the soil side. For example, *Cyperus flavescens* is rampant in the seed and greenhouse planted areas on the soil side but not present in these same sections on the gravel till, although we did not plant the species in either these areas in either substrate. The *Cyperus flavescens* was however planted on in the seed mixture areas on each substrate and may have spread and propagated from this source rather than from the seedbank. If the seed mixture was the source, then it follows that the soil was a more hospitable environment for the germination, survival, and growth of the *Cyperus flavescens* seed. In addition to containing its own seedbank, the hydric soil may function as a more hospitable environment to the seed of other species besides *Cyperus flavescens* which may be blown, washed, or tracked into the site.

4.8.4 Pest Species. Removal of individual cattail seedlings on a weekly basis was found to be a feasible means of preventing an overgrowth problem with this species. Windblown cottonwood and willow species presented a serious problem in this first year. Cottonwood seedlings were subjectively most numerous and easiest to control by direct removal. Willow growth quickly developed a tenacious root system that made physical removal difficult late in the season. Inexperience with identifying these species made it impossible to decide to remove them earlier. In retrospect, it is recommended that both of these species should be removed by pulling as soon as their leaves and stems can be distinguished.

5.0 CONCLUSIONS

5.1 PLANT GROWTH.

5.1.1 Plant Species Performance On Gravel Till Vs Westland Silty Clay Loam (hydric) Soil. Although most plants survived or grew better in the hydric soil, some demonstrated the opposite trend. Both the gravel till and the Westland silty clay loam substrates (two sides) of the constructed fen supported plant species typical of fens in the region. The project demonstrated that a fen can be established using either hydric soil or glacial till as a base. It will probably take several years to determine if the vegetative expression of the fen will be maintained through succession.

5.1.2 Plant Growth From Seed. In general, most species prospered better on the soil substrate when planted from seed, however some species exhibited the opposite trend. A few species were equally successful on either substrate.

5.1.3 Performance of Greenhouse Grown Stock vs Seed. All methods of introducing plants had some degree of success, but some species survived or grew better with one type of planting strategy. Overall, most of the plants planted from greenhouse grown stock performed better than plants introduced as seed. Some species showed the reverse trend and a few did not show a preference.

5.1.4 Plants Transplanted in Plugs from Local Natural Wetlands. Plugs dug from the nearby natural wetlands each developed several species. Many more species were present in the plugs, but were not present in all of the plots or on both substrates, so

it was not possible to directly compare their growth. Even though the plugs placed in the four replicate plots and on each of the two substrates were obtained from the same locations (and therefore environments) in the Beaver Creek wetlands, the species distributions in the plugs were not identical because nature has an element of randomness in it. A multitude of plant species were observed to grow and propagate from the plugs on both substrates in a manner similar to what would be comparable to that observed in the local Beaver Creek wetlands. In general, the species in plugs on the soil side spread outward, sending out more runners and becoming more densely vegetated. The overall vigor of plants, as determined by growth rate and survival was superior on the soil in three of the seven species which showed positive growth rates. The remaining four species exhibited roughly equivalent growth rates on the two substrates.

An error in the measurement methodology, resulted in "bad" height data which misleadingly indicates several plants are "shrinking" or dying back when in reality the plants were actually continuing to grow. If this experiment were to be repeated, changes to the measuring methodology would be required to avoid this problem. Height data is not as important as overall biomass in the following years of growth at this site. Many plants may grow primarily upward in the first growing season and grow mainly outward (increased density and coverage) during subsequent growing seasons. In addition, now that the vegetation has become fairly dense, at least on the soil substrate, the task of determining (seeing) and measuring the height of the tallest plant specimen of each individual species would become excessively difficult and time-consuming.

5.1.5 General Seed Mixture Growth, Biomass Samples From the Seed Mixture Areas, and Moisture Contours. Biomass of a seed mixture, as measured by dry weight, organic content, and phosphate content, was consistently larger on the soil side of the fen. Variance in the values within and between plots on a given substrate correspond strongly with moisture contours. Biomass samples taken in areas with standing water, (<1.0") exhibited notably lower dry weight, organic content, and phosphate content. In addition, the percentage of organic material in the biomass seems to be enhanced in the presence of soil.

5.2 WATER CHEMISTRY.

The water chemistry at the influent, the effluent, and throughout the site was similar to fens seen regionally, throughout the U.S. and worldwide. The ranges are quite large for most of the water chemistry parameters found in natural wetlands, however it appears a critical water chemistry parameter for a fen is the circumneutral (5-9) pH.

The water chemistry on the soil and gravel sides was basically the same, with the exception of lower alkalinity and Ca^{+2} hardness levels on the soil side compared to the gravel side. The alkalinity and Ca^{+2} levels are higher on the gravel substrate because the water is apparently picking up dissolved Ca^{+2} from the gravel till. The water chemistry in the plant root zone (upper 0-6" below the surface) and below the root zone (lower 6-12" below the surface) was basically the same. The pH did not vary in either substrate much (variations were below the detectable limits of the test paper) and this indicates a well-buffered system. Non-conservative nutrients such as nitrate and phosphate were quite low

in both substrates indicating that plants were able to sequester them as rapidly as they were supplied.

Although the chemistry varied from plot to plot and with sample depth it appears that the flow of water maintained a relatively constant chemistry around the roots of the plants (during the growing season). The chemistry of the water around the plant roots is flow dominated and primarily attributed to the chemistry of the deep aquifer water source.

5.3 WATER CONTOURS.

The gravel side of the experiment developed more pools of standing water than the soil side, partially due to the slightly lower elevation of the gravel side and packing or settling of the gravel. The boardwalk also dammed up the water flowing along the surface because the water could not flow under the boards as easily as it could in the soil.

The standing water favored the emergent species like *Alisma subcordatum* and may have inhibited the sedge population growth. The growth of algae in the pools of standing water may have also competed for nutrients with the plants and thereby reduced overall production in the gravel. Very dry areas on the gravel side also corresponded to low plant growth, germination, and survival.

A few hydrological design changes would result in more even water flow and distribution within the site. A manifold with screened supply pipes that are perpendicular to the designed water flowpath would minimize local foci of seepage. Future designs should incorporated a greater slope of the ground surface and the elevation of the boardwalk on the gravel to prevent pooling of water.

5.4 OVERALL.

The plan for construction of this fen was derived from studies of Ohio and United States fens and success was probably based on the following hydrologic features: Continuously flowing groundwater, water that does not accumulate to appreciable depth, and mineral rich groundwater derived from glacial deposits. In addition, the initiation and direction of plant succession was forced by using seed and plant stock derived locally.

Since soil supports a more robust growth of plants it should be used to promote rapid development of fen restorations, but it is not absolutely necessary for success. To avoid introduction of large populations of undesirable species and have most of the benefits of soil, gravelly till could be amended with as little as 1 millimeter of organically rich hydric soil before planting.

5.5 SUCCESSION OF GRAVEL TILL TO SOIL:

Given the continuation of proper hydrologic conditions and water chemistry, and given the initial input of species native to natural fens in the local area, the vegetation on the gravel till side will probably mimic or catch up to the vegetation on the soil side in height, density, and species diversity with time. Peat and thus organic soil matter will be formed on the gravel till as dead plant litter decays. Similarly, chemical changes started in the gravel till when it was saturated and hydric conditions were established. Thus, the gravel till, will progressively mimic the organic hydric soil as time passes (EPA, 1992). The microbes present in the soil will eventually also become established in the gravel till.

Progression has been documented in the literature from vegetation establishment on gravel glacial till to the establishment of a fen under arctic conditions as discussed in sections 2.9.1 and 2.9.2 (Bliss, 1994; Stottlemeyer, 1989). While this progression has been documented to take thousands of years under natural arctic conditions, it should progress much faster in our case. First, biological activities are always much slower under extremely cold conditions versus temperate conditions. Second, we have forced or "jump-started" the succession process by providing an initial input of species native to natural fens in the local area. Third, the close proximity to local fens and the other research sites, will speed succession through the possible input of microbes, providing interaction with native wetland animal species, and providing an added species source by air and other means.

Many species reach a maximum height (such as *Carex* sp) beyond which they continue to grow and propagate outward but no longer increase in height. If the plants are outcompeted and thereby nutrient-limited or limited in space, sunlight or water, then the species may not reach their maximum height under ideal conditions. Although it is reasonable to predict that the plants on the gravel side will catch up in height (and also density) with their counterparts on the soil side if the system is given enough time, we cannot predict this at this time.

6.0 RECOMMENDATIONS FOR FUTURE WORK.

6.1 Continued Monitoring in the Second and Subsequent Years of the Experimental Fen.

Future research should build on the first year data collected in this effort. The progress of the fen site should be tracked for the next several years to follow the succession of the vegetation, soil, and water chemistry. Biomass sampling is recommended as the primary means of objectively measuring the vegetative progress of the individual species in the following years. Because many species grow vegetatively, spreading outward in the subsequent growing seasons, species plant height is not as useful a measuring tool as it was in the first year. In addition, the dense nature of the vegetation would make gathering height data difficult and exceedingly time-consuming. Germination and survival rates are also not relevant in the following growing seasons, but the plot should be watched to determine if the species which failed to germinate in the first growing season (or were so small as to be undetectable), germinate in the second growing season or in subsequent years. However, observational data, regarding the dominant species and overall diversity in the plots would also be useful.

I would also recommend that a stratified random sampling plan be used for biomass sampling. Areas should be divided into two sampling sub-areas, one with no standing water and one with standing water. By doing this the effect of standing water on biomass, organic content, and phosphate content could be better separated from the effect of the substrate type. An unstratified random sampling plan was used to sample the biomass this season. It was necessary to compare the contour plots and the exact

sampling locations after the fact, which was more time consuming than using a stratified random sampling plan would have been.

Additional water chemistry analysis in the subsequent years is recommended. This would serve a few purposes. First, by sampling more frequently throughout the growing season and year-round, any seasonal variations in water chemistry could be documented. Second, it could be determined if the water chemistry changed over the years as the vegetation and soil underwent successional progression. Although the water chemistry is expected to be constant because of the homogeneous nature of the deep water supply, there was insufficient water data in this experiment to determine any variations during the growing season or following years. Lastly, the water chemistry of the upper and lower soil layers on the two substrates could be further compared to identify any progressional changes.

6.2 Research at Other Subscale and Larger Scale Restored Fens. Research could also be done at sites other than the one used in this effort. Anecdotal evidence of significantly increased vegetation height and density in the seeded area of plot #1 of our site following a rain erosion event which applied of a fine layer of soil over the gravel, indicates plant species may grow and prosper as well on a substrate of gravel with a small amount of soil as on a substrate of 6" of soil. A controlled experiment on a constructed site similar to ours could be conducted to investigate these preliminary findings.

We have learned that substrate differences do not have the same impact on different species. Even different species in the same genus, such as mints (*Mentha* spp), were observed to react differently. Therefore, it is recommended that additional plant

species in Ohio as well as in other parts of the country and world on sites be investigated. This could be done on experimental sites similar to ours or on larger scale fen restoration projects.

Specifically, the collection of germination, survival, plant height, biomass, and water chemistry data from larger scale fen restoration projects planned in Ohio is recommended. This data would provide additional data on the species examined in this project as well as yield similar insight on the success of species not studied. It might also provide insight into the growth and successional progression of species in a much larger setting.

7.0 FEN CREATION OR RESTORATION DECISION MATRIX

The germination, survival, plant height, biomass, and water chemistry data collected in this effort and in future efforts will help guide persons undertaking the restoration of a fen to balance design requirements with project resources. This data could be compiled into a more user-friendly format such as a computer database or guidance manual which would detail the relative growth of individual species in soil and gravel till substrates.

When a fen restoration project is being undertaken, several design criteria and resource limitations must be taken into account. There are funding, manpower, time, equipment (heavy machinery), land (location), or species specimen availability (seed, greenhouse stock, or natural plug) constraints. Design criteria may include the requirement for the establishment of a certain percentage of vegetative coverage within an established period of time. Establishing a large degree of biodiversity or planting and propagating one or more endangered plant species may also be design requirements.

Our experiment yielded insight into the degree of success individual species experienced in the first year of growth on a soil substrate compared to a gravel till given different planting methods. The serendipitous application of a fine layer of soil to the seed area of plot #1 on the gravel side, and the subsequent heavy growth in height and density in the location, also provides insight into the use of such a substrate combination. Follow-on research could provide insight into the growing patterns in subsequent years. Armed with this information, the planner can make decisions regarding which species to plant,

what planting methods to use for which species, and whether to use gravel till, organic substrate, or some combination of the two.

The planner may go through a decision-making process similar to the one described below which first considers how rapidly dense vegetation is required or desired. If it must be established "quickly" and the seedbank is required, then a planner might use full soil substrate and greenhouse stock. If it must be established rapidly but the seedbank is not needed or wanted, then a gravel substrate with a fine layer of soil planted with greenhouse stock would be recommended. If a somewhat longer period of time may pass before dense vegetation is established, one might use a combination of soil substrate and seeding, or gravel substrate and greenhouse planting. If an even longer amount of time is acceptable, then a gravel substrate planted with seed could be used.

If the restoration manager decides to plant in gravel substrate, the first decision required would be which species to plant. Second, the manager would determine from the database or handbook which planting method, greenhouse stock or seeding, yielded the best results for those species on gravel till for each individual species. If the species prospers in gravel with one planting method then that method should be employed. If the species prefers gravel substrate with either planting method then the easier or least expensive method, which is usually seeding, should be used.

Increased growth and survival are often traded off with cost and schedule. Seeding costs less and takes less manpower than planting from greenhouse stock. However, compared to seeding, planting with greenhouse grown stock often results in greater robustness of plants, increased propagation, and the advent of seed production in

the first growing season. Individual plant specimens, planted from seed, are much less apt to produce seed in the first growing season, than plant specimens planted from greenhouse stock. The seed produced in the first growing season can then germinate to fill in all the open spaces in the second year. Thus, generally greater vegetative coverage can be achieved in a shorter period of time by planting with greenhouse stock rather than from seed. Gravel substrate costs less, is easier to handle, and makes it easier to locate the wetland, but may result in reduced growth and survival for some species. If one is using seed mixture, than adding more of the species which have lower survival or growth rates will help ensure representation of these species and in turn higher biodiversity. Increased amounts of seed may cost more, but it may also avoid the need to reseed at a later time. Similarly, using greenhouse stock, one might plant more specimens of the less "prosperous" species to ensure their representation, also at an added cost. It may avoid the expense and effort of replanting in the future however.

Since it is not possible to make blanket statements that all species prefer a particular substrate type or planting method, the data gathered in this study will provide valuable information on individual species. Future work may provide similar information on additional species to the restoration planner. The overall goal is to build the most "prosperous" wetland in the most efficient means possible, i.e. for the lowest cost, time, manpower, etc.

Appendix A -- Water Chemistry of Fens and Bogs from the literature

Author	Location/Type	pH	Ca^{2+} mg/L	Mg^{2+} mg/l	Conductivity umhos (uncorrected for hydrogen ions)	Soluble PO_4 mg/l	Iron mg/l	NO_3 mg/l	NH_3 mg/l	Sulfate mg/l	Alkalinity mg/l
Fen -- After a Rain											
Amon (unpublished)	Sandhills, NB (after rain) (1995)	6.0	17	51	80.7*	0.08	0.22** high end	2.629	0.011	36	13.6
Fens -- Alpine Locations											
Amon (unpublished)	Mt Evans Summit Lake Pool, CO (1995)	6.7	17	51	48.7*	0.06	0.15	1.089	0.011	6	13.6
Amon (unpublished)	Silver Dollar, CO (1995)	6.9	17	51	48.1*	0.03	0.04	1.308	0.012	1	20.4 (5 ml sample)
Amon (unpublished)	Jefferson, CO (1995)	7.8	187	204	420.0	0.06	0.025	2.826 (farmed)	0.254	9	95.2
Amon (unpublished)	Rocky Mountain Natl Park, CO (1995) (beaver pond nearby)	6.4	17	68	109.2	0.02	0.25 (high end)	0.838	0.042	10	27.2
Amon (unpublished)	Kenosha Marsh, CO (1995)	7.5	170	170	797.0	0.13	0.17	0.876	0.004	27	95.2
Fens -- Non-alpine locations											
Carol Thompson (unpublished)	Evans, IA (Jun 1989-Jun 1990)	6.78-7.53	72-80	26-40	364-480	n.d. < 0.01	0.5	0.1-0.4	< 0.1	12	199-442
Amon (unpublished)	Fen Valley, IA (8/1995)	7.7	187	51	551.0	0.04	0.01	5.487 (farmed)	0.013	41	136.0
Carol Thompson (unpublished)	Fen Valley, IA (Jun 1989-Jun 1990)	7.32-7.94	68-91	27-71	410-560	n.d. < 0.01	1.4	0.7-2.4	< 0.1	75-76	288-392
Amon (unpublished)	Beardmore, IA (1995)	7.1	119	17	266.0	0.20	0.005	1.074	0.027	62	54.4
Carol Thompson (unpublished)	Beardmore, IA (Jun 1989- Jun 1990)	6.35	124	22	640.0	n.d. < 0.01-		< 0.1	< 0.1	354	126.0

Author	Location/Type	pH	Ca^{2+} mg/L	Mg^{2+} mg/l	Conductivity umhos (uncorrected for hydrogen ions)	Soluble PO_4 mg/l	Iron mg/l	NO_3 mg/l	NH_3 mg/l	Sulfate mg/l	Alkalinity mg/l
Amon (unpublished)	Berning, IA (1995)	7.2	204	85	715.0	0.20	0.015	1.087	0.014	40	250.6
Carol Thompson (unpublished)	Berning, IA (Jun 1989-Jun1990)	6.93-7.58	73-92	27-83	460-560	n.d. < 0.01	0.1	< 0.1-0.2	n.d. < 0.1	69-87	338-402
Amon (unpublished)	Barton, IA (1995)	7.8	255	51	553.0	0.01	0.02	15.827	0.014	34	149.6
Carol Thompson (unpublished)	Barton, IA (Jun 1989-Jun1990)	6.86-7.45	88-105	26-52	465-680	n.d. < 0.01	0.5	0.1-0.4	n.d. < 0.1	96-185	205-414
Amon (unpublished)	Silver Lake, IA (1995)	8.0	731	306	1970.0	0.04	0.01	0.649	0.011	87	210.8
Carol Thompson (unpublished)	Silver Lake, IA (Jun 1989-Jun 1990)	6.79-7.16	330-389	84-152	1100-2000	n.d. < 0.01	2.4	n.d. < 0.01	n.d. < 0.1	1120-1305	230-386
Amon (unpublished)	Oak hill, IL (1995)	7.9	221	119	611.0	0.14	0.02	11.345	0.095	60	136.0 (10 ml sample)
Amon (unpublished)	Cedar Bog (fen), OH (1995)	7.9	260-280	120-160	642.0-740.0	n.d. < 0.01	.08-.12	.030-.060	n.d. < 0.1	75	
Amon (unpublished)	Gallagher Fen, OH (1995)	7.65	220	180	681.0	n.d. < 0.01	0.06-0.12	.060-.090	n.d. < 0.1	54	<385
Amon (unpublished)	Springville Marsh (fen), OH (1995)	7.3			524.0-628.0	n.d. < 0.01		0.2-0.5			
Amon (unpublished)	Fishcreek Fen, IN (1995)	6.5	160	60	454.0-491.0	n.d. < 0.01	0.1	n.d. < 0.01		27	
Amon (unpublished)	Laketon Bog (fen), IN (1995)	6.74	280	0	630.0-698.0	< 0.01	0.12	n.d. < 0.01		0	
Carol Thompson (unpublished)	Leith (Jun 1989-Jun 1990)	6.93-7.58	87-100	29-42	380-600		8.4-11.0	15.6-18.0	n.d. < 0.1	31-37	2.8-5.1
Carol Thompson (unpublished)	Kleve (Jun 1989-Jun 1990)	7.18	265	77	890		5.5	0.40	0.9	668	0.3
Carol Thompson (unpublished)	Excelsior (Jun 1989-Jun 1990)	7.05-7.43	156-176	44-74	725-1500		276-452	<.1-.4	n.d. < 0.1	383-597	276-452

Author	Location/Type	pH	Ca^{2+} mg/L	Mg^{2+} mg/l	Conductivity umhos (uncorrected for hydrogen ions)	Soluble PO_4 mg/l	Iron mg/l	NO_3 mg/l	NH_3 mg/l	Sulfate mg/l	Alkalinity mg/l
Carol Thompson (unpublished)	Valen (Jun 1989-Jun 1990)	6.9-7.55	110	47	470-700		370-598	<.1	<0.1-0.3	99.000	338-598
Carol Thompson (unpublished)	White (6/1989-6/1990)	6.91-7.49	102-124	38-46	415-640		316-402	<.1-.3	n.d. < 0.1	126-139	316-402
Carol Thompson (unpublished)	Kinney Lindstrom (Jun 1989-Jun 1990)	7.25-7.62	96-98	29-57	365-610		0.4	<.1-6.6	n.d. < 0.1	79-110	240-274
Carol Thompson (unpublished)	Schumann (Jun 1989-Jun 1990)	6.67-8.01	103	22	660		2.5	0.20	n.d. < 0.1	259.0	118
Carol Thompson (unpublished)	Boeding Tank (Jun 1989-Jun 1990)	6.83-7.16	62-76	10-19	320-950		0.8	< 0.1-0.4	n.d. < 0.1	42-51	176-258
Carol Thompson (unpublished)	Roose (Jun 1989-Jun 1990)	7.14-7.85	88-90	14-24	353-550		1.1	.1-2.6	< 0.1-1.0	46.000	292-376
Carol Thompson (unpublished)	Chapman (Jun 1989-Jun 1990)	6.89-6.97	69-103	10-23	405-580		1.6	0.30	10	14-84	176-540
Carol Thompson (unpublished)	Brayton (Jun 1989-Jun 1990)	6.3-7.45	32-57	4-12	240-340		2.2	14.00	n.d. < 0.1	30.000	22-112
Carol Thompson (unpublished)	Schulte (Jun 1989-Jun 1990)	6.96-7.53	46-48	2-5	260-280		0.5	17.00	n.d. < 0.1	20-27	63-102
Carol Thompson (unpublished)	Rowley (Jun 1989-Jun 1990)	7.26-7.86	82-95	14-22	400-520		1.2	.1-2	< 0.1-0.1	65-69	246-292
Charlton et al. (1988)	Bruce Peninsula, Ontario	6.3-7.3	27-222	10-39	260-440						
Sims et al.(1982)	South James Bay, Ontario	4.2-7.3	1.5-45.5	0.4-20.5	30-800						
Sjors (1963)	Attawapiskat River James Bay, Ontario	4.8-7.4	1.7-8.9	0.5-1.8	22-48*						
Vitt et al. (1975)	North-central Alberta	5	2.4	0.4							
Heinselman (1970)	North Michigan	5.3-6.4	5-10.6	0.1-2.8	31-91*						

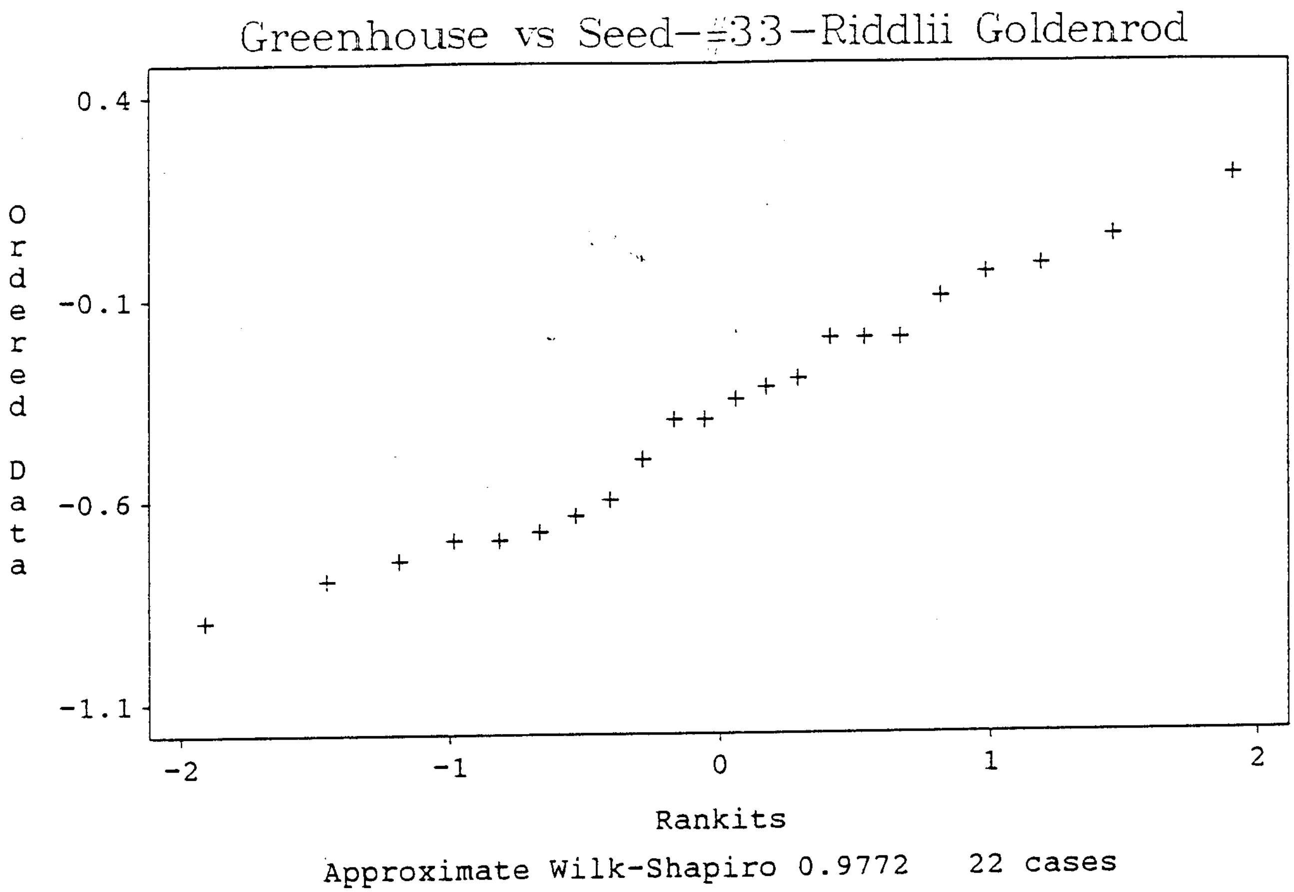
Author	Location/Type	pH	Ca^{2+} mg/L	Mg^{2+} mg/l	Conductivity umhos (uncorrected for hydrogen ions)	Soluble PO_4 mg/l	Iron mg/l	NO_3 mg/l	NH_3 mg/l	Sulfate mg/l	Alkalinity mg/l
Schwintzer (1978)	North Michigan	5.7-7.0	11-75	2.8-17.8	29-228						
Slack et al. (1980)	West Alberta	6.8-7.9	18-37	4-18	140-456						
Glaser (1983) (excluding poor fens)	North Minnesota	5.6-6.2	3.6-30.4		35-115*						
Seischab (1984)	West New York	7.9	326-361	58-60	1496-1569						
Nordqvist (1965)	Jamtland, Sweden	6.6-7.6	25-109		145-592						
Moore & Bellamy (1974)	Transitional (poor) Fens - Western Europe (mean values)	4.1-4.8									
Moore & Bellamy (1974)	Minerotrophic fens - Western Europe (mean values)	5.6-7.5									
Bares & Wali (1979)	Minnesota, USA - Alkaline peat - *Larix laricina* stand	6.7-7.1	3.5-5.4 meq/100g	2.7-6.5 meq/100g							
Bares & Wali (1979)	Minnesota, USA - Alkaline peat - *Picea mariana* stand	5.7-6.4	3.5-10.5 meq/100g	1.5-6.0 meq/100g							
Malmer & Sjors (1955)	Sweden - Marginal fen	5.2	19.5 meq/100g								

Author	Location/Type	pH	Ca^{2+} mg/L	Mg^{2+} mg/l	Conductivity umhos (uncorrected for hydrogen ions)	Soluble PO_4 mg/l	Iron mg/l	NO_3 mg/l	NH_3 mg/l	Sulfate mg/l	Alkalinity mg/l
Richardson et al. (1978)	Michigan, USA - Rich fen	5.1	52.4 meq/100g	7.7 meq/100g							
Gorham (1956)	England - English Lake District - Fen	6.1-7.6	2.3-17.5 meq/100g								
Mitsch and Gosselink (1986)	Fens (in general)		200-500 meq/L								
J.A. Wood and C.D.A. Rubec (1989)	Extremely poor fen/transitional bog - Kejimkujik National Park, Nova Scotia (surface water)	4.58	0.03 epm	0.04 epm			0.09 epm			0.06 epm	
Riley (1988)	FEN - Southern Ontario off the Canadian Shield	5.0 - 7.0	39.8	3.1	206						
Wassen, et al. (1990)	Fens - Biebrza valley mire, Poland (Jul 1987)	6.6-7.5	24-102			0.00-0.27	0.34-1.87				
D.L.Charlton (1988)	Fens - Bruce Peninsula, Canada (9 sites)	6.8 +- 0.4	82 +- 55	20 +- 8	344 +- 54						
D.L.Charlton (1988)	Rich Fens - Bruce Peninsula, Canada (9 sites)	6.9 +- 0.5	102 +- 57	22 +- 9	360 +- 60						
D.L.Charlton (1988)	Poor Fens - Bruce Peninsula, Canada (9 sites)	6.6 +- 0.3	42 +- 11	17 +- 2	313 +- 12						

Author	Location/Type	pH	Ca^{2+} mg/L	Mg^{2+} mg/l	Conductivity umhos (uncorrected for hydrogen ions)	Soluble PO_4 mg/l	Iron mg/l	NO_3 mg/l	NH_3 mg/l	Sulfate mg/l	Alkalinity mg/l
BOGS											
J.A. Wood and C.D.A. Rubec (1989)	*Bog - Kejimkujik National Park, Nova Scotia (surface water)*	*4.24*	*0.03 epm*	*0.02 epm*			*0.19 epm*			*0.05 epm*	
Damman & French (1987)	*Newfoundland, Canada - Ombrotrophic bog*		*0.25+-0.2 meq/100g*	*.46+-0.2 meq/100g*							
Damman & French (1987)	*Newfoundland, Canada - Minerotrophic bog*		*2.8+-.36 meq/100g*	*1.11+-0.06 meq/100g*							
Gorham (1956)	*England - English Lake District - Raised Bog*	*4.0-4.3*	*1.3-1.8 meq/100g*								
Walsh & Barry (1958)	*Ireland - Raised bog*	*4.7*	*2.0-4.0 meq/100g*								
Gore & Allen (1956)	*England - Blanket bog*		*4.3 meq/100g*	*4.6 meq/100g*							
Riley (1988)	*BOG - Southern Ontario off the Canadian Shield*	*3.6 - 4.7*	*3.0*	*0.4*							
Amon (unpublished)	*Triangle Lake Bog, OH (1995)*	*4.7*	*116*	*54*	*50.3*		*1.25*				

Author	Location/Type	pH	Ca^{2+} mg/L	Mg^{2+} mg/l	Conductivity umhos (uncorrected for hydrogen ions)	Soluble PO_4 mg/l	Iron mg/l	NO_3 mg/l	NH_3 mg/l	Sulfate mg/l	Alkalinity mg/l
BOGS											
Amon (unpublished)	*Browns Lake Bog, OH (1995)*	*4.7*	*65*	*54*	*37.6*		*1.2*				
Mitsch and Gosselink (1986)	*Bog*		*13-160 meq/L*								
Heilman (1968)	*Alaska, USA - Black spruce bog*	*3.6-4.0*	*15-16 meq/100g*	*5.3-6.4 meq/100g*							
Moore & Bellamy (1974)	*Ombrotrophic bog - Western Europe (mean values)*	*3.8*									
Malmer & Sjors (1955)	*Sweden - Ombrotrophic Bog*	*3.2*	*5.0 meq/100g*	*1.83 meq/100g*							
KEY:											
* = Low value for a typical fen											
** = High value for a typical fen											

Appendix B - Example of Rankit Plot and Wilk-Shapiro (WS) Test Value for a Normal Data Set



Appendix C - Normality of Modified Height Data Sets Comparing Growth on the Two Substrates as Represented by Wilk Shapiro Test Values

Species #	Species	Wilk Shapiro Test Values Greenhouse	Seed
1	*Carex hystricina* (Porcupine Sedge)	0.9374	0.9768
2	*Mentha* sp (Mint)	**0.4768***	0.9370
3	*Pedicularis lanceolata* (Swamp Loosewort)	NA	NA
4	*Carex stricta* (Tussock Sedge)	0.9566	0.9599
5	*Carex lurida* (Shallow Sedge)	0.8474	0.9267
6	*Cacalia sauveolens* (Sweet-scented Indian Plaintain)	0.8751	0.9198
7	*Carex lupuliformis* (False Hop Sedge	0.8632	0.9729
8	*Carex stipata*	0.9400	0.9560
9	*Carex vulpinoidea*(Fox Sedge)	0.9352	0.9733
10	*Chelone glabra* (Turtlehead)	0.9678	**0.6212***
11	*Potentilla fruticosa* (Shrubby Cinquefoil)	NA	NA
12	*Eupatoriadelphus maculatus* (Joe Pye)	0.9700	0.9204
13	*Eupatorium perfoliatum* sp (Boneset)	0.9828	0.9763
14	*Carex Frankii* (Frank's Carex)	0.9525	0.9738
15	*Filipendula rubra* (Queen of the Prairie)	0.9683	NA
16	*Pycnanthemum* (Mountain Mint)	NA	NA
17	*Gentiana clausa* (Closed Gentain)	NA	NA
18	*Asclepias incarnata* (Swamp milkweed)	0.9435	0.9470
19	*Juncus articulatus* (Jointed Rush)	0.9726	0.9655
20	*Juncus torreyii* (Torrey's Rush)	0.9522	0.8911
21	*Lobelia Cardinalis* (Cardinal Flower)	NA	NA
22	*Mentha* 2 sp (Mint 2)	0.9186	0.8464
23	*Carex prairea* (Prairie Sedge)	0.9528	0.9496
24	*Mentha* 3 sp (Mint 3)	0.9482	**0.4333***
25	*Carex cristatella* (Crested Sedge)	0.9260	0.9321
26	*Sanguisorba canadensis* (Canada Burnet)	0.9200	**0.3719***
27	*Physostegia purpurea* (Purple Dragon-head)	NA	NA
28	*Scirpus pendula* (Drooping Bulrush)	0.9825	0.9405
29	*Thelypteris thelypteroides* (Marsh fern)	NA	NA
30	*Scirpus validus* (Soft-stem Bulrush)	0.9215	0.9528
31	*Verbena hastada* (Blue Vervain)	0.8971	**0.5564***

32	*Angelica atropurpurea* (Great Angelica)	0.9218	**0.6767***
33	*Solidago riddelli* (Riddell's goldenrod)	0.9772	NA

(Wilk Shapiro Value (WS): * indicates WS<0.8

Appendix D - Biomass Data and Calculations

Gravel (1) or Soil (2)	Plot #	Sample # (4=avg)	Al Foil wt	Al + Wet Sample wt	Al + Dry Sample	Water wt	Sample Wet wt	Sample Dry wt	% Water wt	Foil wt	Foil + ~1g ground sample	sample wt	Ash + Foil wt	Ash wt	Organic Content wt	% Organic Content	Phosphate of Ash	Biomass Phosphate
1	1	1	13.97	26.31	16.84	9.47	12.34	2.87	76.742	1.32	2.33	1.01	1.42	0.1	0.91	90.10	0.090	1.560
1	1	2	14.05	64	24.64	39.36	49.95	10.59	78.799	1.33	2.33	1.00	1.43	0.1	0.90	90.00	0.091	47.070
1	1	3	14.08	16	14.64	1.36	1.92	0.56	70.833	1.33	1.91	0.58	1.39	0.06	0.52	89.66	0.100	2.570
1	***1***	***4***	***14.033***	***35.437***	***18.707***	***16.730***	***21.403***	***4.673***	***75.458***	***1.327***	***2.190***	***0.863***	***1.413***	***0.087***	***0.777***	***89.918***	***0.094***	***17.067***
1	2	1	15.95	18.64	16.56	2.08	2.69	0.61	77.323	1.32	1.76	0.44	1.37	0.05	0.39	88.64	0.120	3.080
1	2	2	15.46	19.79	16.44	3.35	4.33	0.98	77.367	1.32	2.06	0.74	1.42	0.1	0.64	86.49	0.096	5.890
1	2	3	14.52	29.25	17.64	11.61	14.73	3.12	78.819	1.34	2.33	0.99	1.44	0.1	0.89	89.90	0.078	14.000
1	***2***	***4***	***15.310***	***22.560***	***16.880***	***5.680***	***7.250***	***1.570***	***77.836***	***1.327***	***2.050***	***0.723***	***1.410***	***0.083***	***0.640***	***88.341***	***0.098***	***7.657***
1	3	1	15.76	38.74	20.17	18.57	22.98	4.41	80.809	1.33	2.33	1.00	1.44	0.11	0.89	89.00	0.084	21.560
1	3	2	18.78	58.14	26.02	32.12	39.36	7.24	81.606	1.33	2.32	0.99	1.46	0.13	0.86	86.87	0.046	42.250
1	3	3	14.75	44.95	20.62	24.33	30.20	5.87	80.563	1.33	2.34	1.01	1.42	0.09	0.92	91.09	0.036	23.250
1	***3***	***4***	***16.430***	***47.277***	***22.270***	***25.007***	***30.847***	***5.840***	***80.993***	***1.330***	***2.330***	***1.000***	***1.440***	***0.110***	***0.890***	***88.986***	***0.055***	***29.020***
1	4	1	10.64	36.65	15.68	20.97	26.01	5.04	80.623	0.99	2.33	1.34	1.13	0.14	1.20	89.55	0.104	23.400
1	4	2	15.20	29.48	17.97	11.51	14.28	2.77	80.602	1.33	2.33	1.00	1.42	0.09	0.91	91.00	0.102	11.080
1	4	3	16.40	75.43	27.18	48.25	59.03	10.78	81.738	0.98	2	1.02	1.09	0.11	0.91	89.22	0.064	51.670
1	***4***	***4***	***14.080***	***47.187***	***20.277***	***26.910***	***33.107***	***6.197***	***80.988***	***1.100***	***2.220***	***1.120***	***1.213***	***0.113***	***1.007***	***89.923***	***0.090***	***28.717***
2	1	1	15.20	39.24	21.46	17.78	24.04	6.26	73.96	1.34	2.34	1.00	1.42	0.08	0.92	92.00	0.070	22.260
2	1	2	15.45	34.42	20.62	13.8	18.97	5.17	72.746	1.35	2.32	0.97	1.43	0.08	0.89	91.75	0.020	18.950
2	1	3	15.70	42.94	23.04	19.9	27.24	7.34	73.054	1.34	2.33	0.99	1.41	0.07	0.92	92.93	0.056	23.070
2	***1***	***4***	***15.450***	***38.867***	***21.707***	***17.160***	***23.417***	***6.257***	***73.254***	***1.343***	***2.330***	***0.987***	***1.420***	***0.077***	***0.910***	***92.227***	***0.049***	***21.427***
2	2	1	17.30	48.69	24.85	23.84	31.39	7.55	75.948	1.33	2.34	1.01	1.41	0.08	0.93	92.08	0.100	26.580
2	2	2	13.68	43.57	20.82	22.75	29.89	7.14	76.112	1.34	2.33	0.99	1.43	0.09	0.90	90.91	0.032	28.850
2	2	3	17.15	26.21	19.64	6.57	9.06	2.49	72.517	1.33	2.33	1.00	1.42	0.09	0.91	91.00	0.064	9.960
2	***2***	***4***	***16.043***	***39.490***	***21.770***	***17.720***	***23.447***	***5.727***	***74.859***	***1.333***	***2.333***	***1.000***	***1.420***	***0.087***	***0.913***	***91.329***	***0.065***	***21.797***
2	3	1	16.49	43.98	23.13	20.85	27.49	6.64	75.846	1.34	2.33	0.99	1.43	0.09	0.90	90.91	0.080	26.820
2	3	2	14.89	74.31	29.27	45.04	59.42	14.38	75.799	1.34	2.33	0.99	1.43	0.09	0.90	90.91	0.082	58.100
2	3	3	15.28	49.54	23.58	25.96	34.26	8.30	75.773	1.35	2.33	0.98	1.43	0.08	0.90	91.84	0.066	30.110
2	***3***	***4***	***15.553***	***55.943***	***25.327***	***30.617***	***40.390***	***9.773***	***75.806***	***1.343***	***2.330***	***0.987***	***1.430***	***0.087***	***0.900***	***91.218***	***0.076***	***38.343***
2	4	1	14.31	70.37	22.69	47.68	56.06	8.38	85.052	1.33	2.34	1.01	1.44	0.11	0.90	89.11	0.040	40.560
2	4	2	17.34	97.62	32.05	65.57	80.28	14.71	81.677	1.33	2.33	1.00	1.43	0.1	0.90	90.00	0.058	65.380
2	4	3	15.52	28.73	17.53	11.2	13.21	2.01	84.784	1.34	2.35	1.01	1.68	0.34	0.67	66.34	0.036	30.070
2	***4***	***4***	***15.723***	***65.573***	***24.090***	***41.483***	***49.850***	***8.367***	***83.838***	***1.333***	***2.340***	***1.007***	***1.517***	***0.183***	***0.823***	***81.815***	***0.045***	***45.337***

Appendix D -- Key to the Biomass Spreadsheet

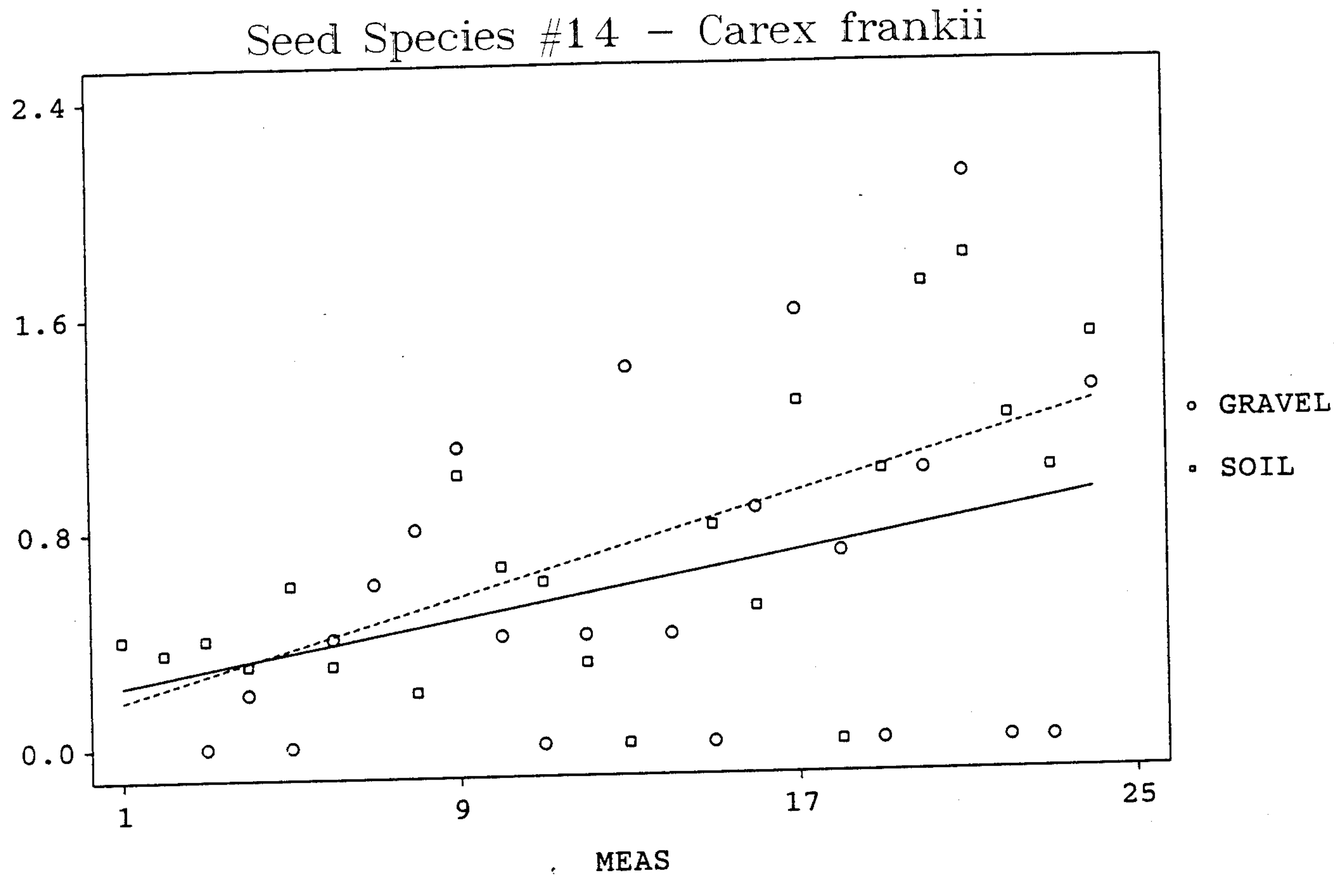
1. Gravel (1) or Soil (2) substrate
2. Plot # (1, 2, 3, or 4)
3. Sample # (1, 2, or 3; 4 is the average of 1-3)
4. Al Foil wt = weight of the aluminum foil the sample was wrapped in
5. Al + Wet Sample wt = weight of the wet biomass sample wrapped in the aluminum foil
6. Al + Dry Sample = weight of sample and aluminum foil after the drying process
7. Water wt = weight of the water contained in the biomass sample (weight "lost" during the drying process)
8. Sample Wet Wt = biomass sample weight prior to drying (subtracting the weight of the aluminum foil)
9. Sample Dry Wt = weight of the biomass sample following drying (subtracting the weight of the aluminum foil)
10. Dry Wt/Area = biomass dry weight per surface area sampled (per 15cm x 15 cm = 225 cm^2)
11. % Water wt = percent of biomass wet weight which is water (ie how much of wet weight is lost during the drying process)
12. Foil wt = the foil tray ground dried biomass subsamples are placed in prior to ashing
13. Foil +~1g ground sample = foil subsample tray with roughly 1 gram of ground dried biomass sample (sometimes less than 1g was used when the dried biomass sample was smaller than 1g)
14. Sample wt = ground dried biomass sample weight (foil plus ground sample minus foil weight)
15. Ash + Foil wt = Weight of the foil tray plus the ashed subsample after ashing process
16. Ash wt = weight of ash alone (subtracting the foil tray weight)
17. Organic Content wt = weight "lost"/volatilized during the ashing process
18. % Organic Content = [Organic Content wt/ground sample wt(#14)] x 100%.
19. PO_4
20. Biomass

Appendix E -- Plug Species Height Data Sheet

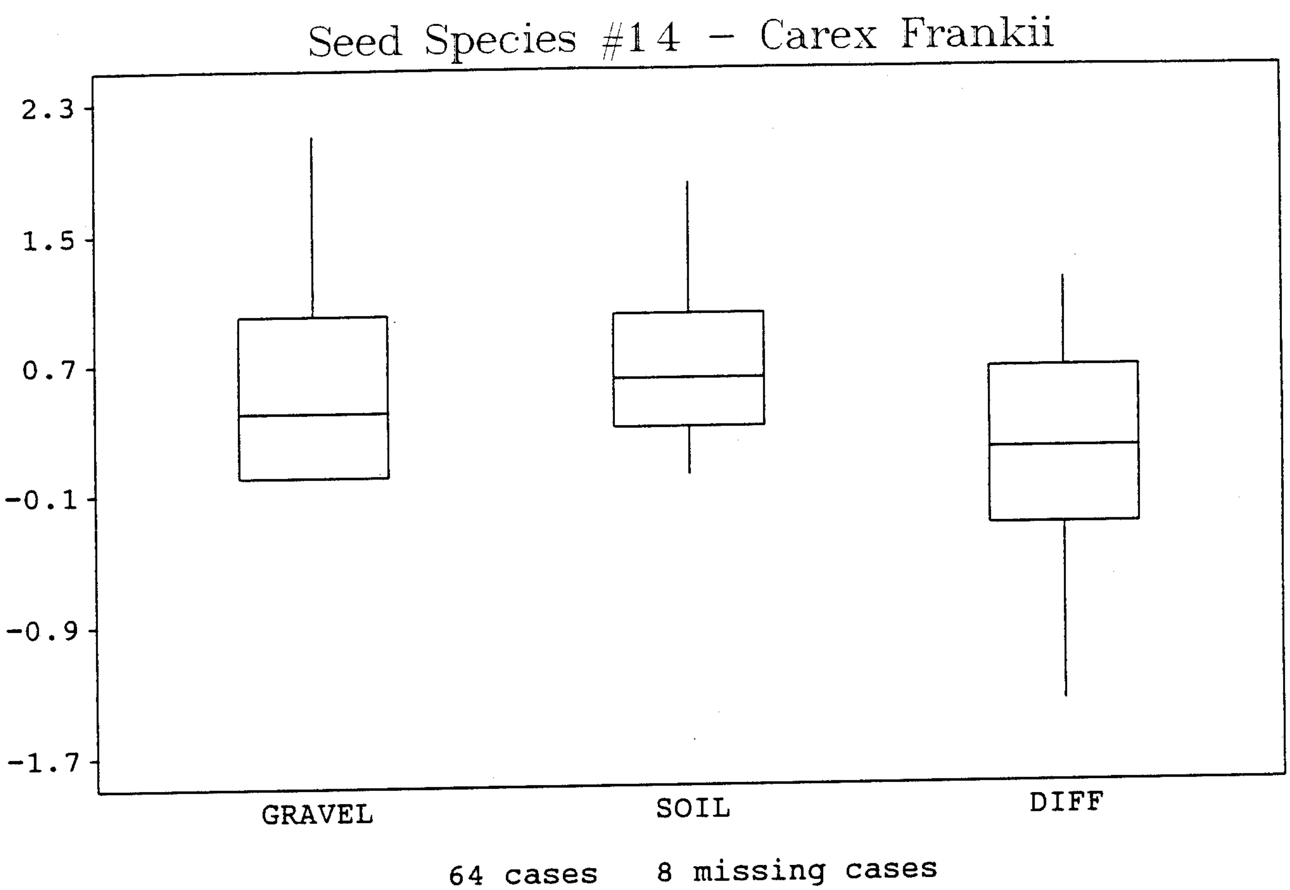
Date:	Soil Type: Gravel Soil	Plot #: 1 2 3 4	Origin: PLUGS	Name:
-16	-17	-18	-19	-20
-11	-12	-13	-14	-15
-6	-7	-8	-9	-10
-1	-2	-3	-4	-5

APPENDIX F	One-Sided p-Values (soil>gravel) or (greenhouse>seed)		
Species #	Species	Greenhouse	Seed
1	*Carex hystricina* (Porcupine Sedge)	*0.0000* ******	**0.0746** **
2	*Mentha* sp (Mint)	0.1625 * 1 tail WSR	0.4671
3	*Pedicularis lanceolata* (Swamp Loosewort)	NA	NA
4	*Carex stricta* (Tussock Sedge)	0.0083 ***	0.0898 **
5	*Carex lurida* (Shallow Sedge)	0.1822 *	0.0001 ****
6	*Cacalia sauveola* (Sweet-scented Indian Plantain)	0.0026 ***	0.0003 ****
7	*Carex lupuliformis* (False Hop Sedge)	0.4925	0.3138
8	*Carex stipata*	0.0572 **	*0.0000* ******
9	*Carex vulpinoidea* (Fox Sedge)	0.0043 ***	0.0541 **
10	*Chelone glabra* (Turtlehead)	**0.2033**	**0.1577** *
11	*Potentilla fruticosa* (Shrubby Cinquefoil)	NA	NA
12	*Eupatoriadelphus maculatus* (Joe Pye)	0.0470	0.0000 ****** 1 tail WSR
13	*Eupatorium perfoliatum* (Boneset)	*0.0000* ******	0.2909
14	*Carex Frankii* (Frank's Sedge)	0.0002 ****	0.6133
15	*Filipendula rubra* (Queen of the Prairie)	NA	NA
16	*Pycnanthemum*	NA	NA
17	*Gentiana clausa* (Closed Gentain)	NA	NA
18	*Asclepias incarnata* (Swamp milkweed)	0.0003 ****	0.0028 ***
19	*Juncus articulatus* (Jointed Rush)	0.0039 ***	0.0213 **
20	*Juncus torreyi* (Torrey's Rush)	0.0026 ***	0.0496 **
21	*Lobelia Cardinalis* (Cardinal Flower)	NA	NA
22	*Mentha* sp 2 (Mint)	***0.0000*** ****	**0.0169** **
23	*Carex prairea* (Prairie Sedge)	0.0362 **	0.0953 **
24	*Mentha* sp 3 (Mint)	0.0062 ***	0.6250 1 tail WSR
25	*Carex cristatella* (Crested Sedge)	0.1101 *	*0.0000* ******
26	*Sanguisorba canadensis* (Canada Burnet)	0.4075	0.2891 1 tail WSR
27	*Phytosegia purpurea* (Purple Dragon-head)	NA	NA
28	*Scirpus pendula* (Drooping Bulrush)	0.0978 **	0.013 *
29	*Thelypteris thelypteroides* (Marsh fern spores)	NA	NA
30	*Scirpus validus* (Soft-stem Bulrush)	0.0097 ***	0.0035 ***
31	*Verbena hastada* (Blue Vervain)	0.0958 **	0.5000 1 tail WSR
32	*Angelica atropurpurea* (Great Angelica)	0.0124 **	**0.0020**
33	*Solidago riddelii* (Riddel's Goldenrod)	*0.0000* ******	NA
	KEY: ****** = p=*0.0000* **=*p<0.1000*		
	*** = p<0.0100 *=p<0.2000	**bold type** = gravel>soil or seed >greenhouse	

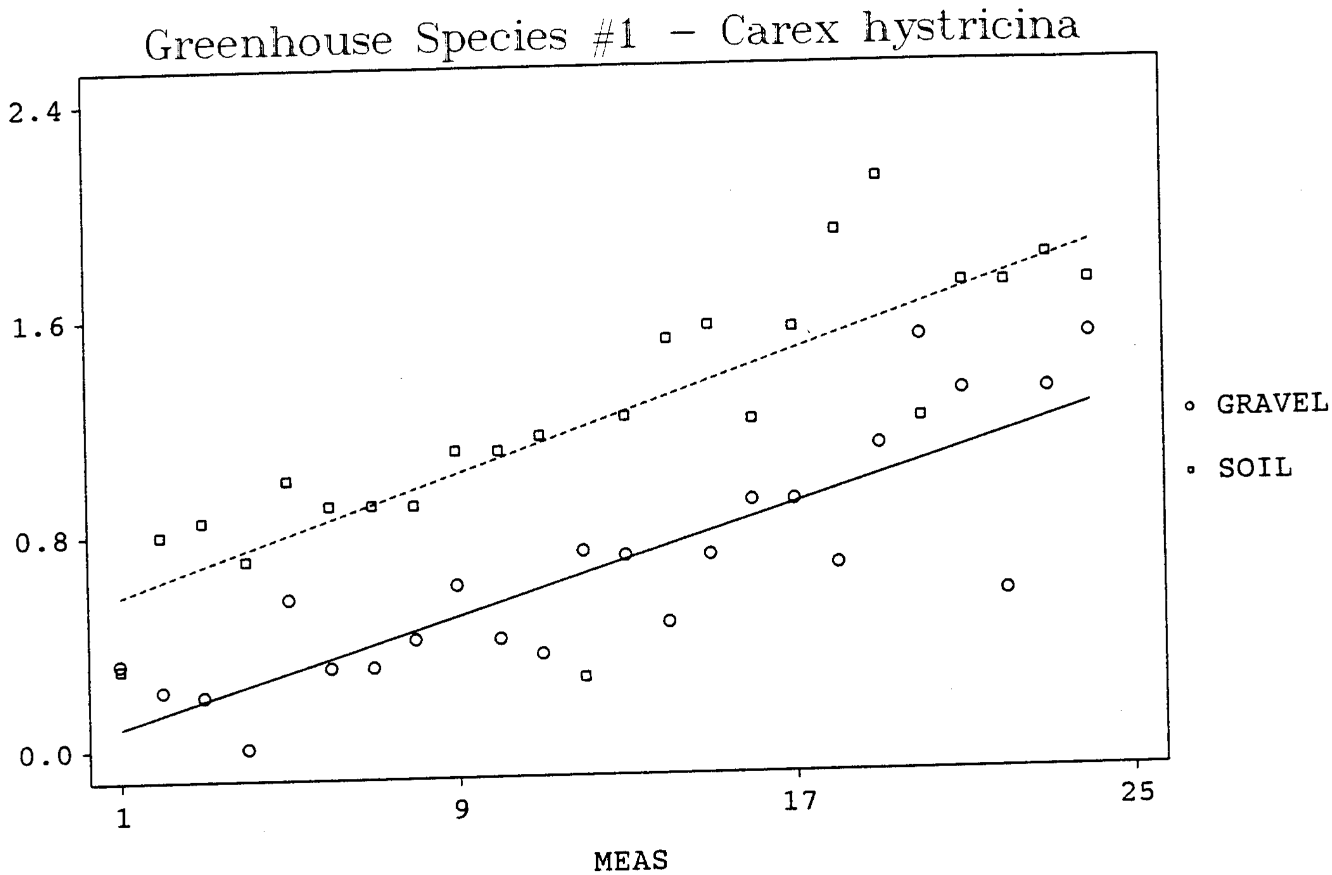
Appendix G -- Example of Equal (not significantly different) Growth on Either Soil or Gravel Till per Modified Height Data on Species Planted form Seed - (Scatterplot)



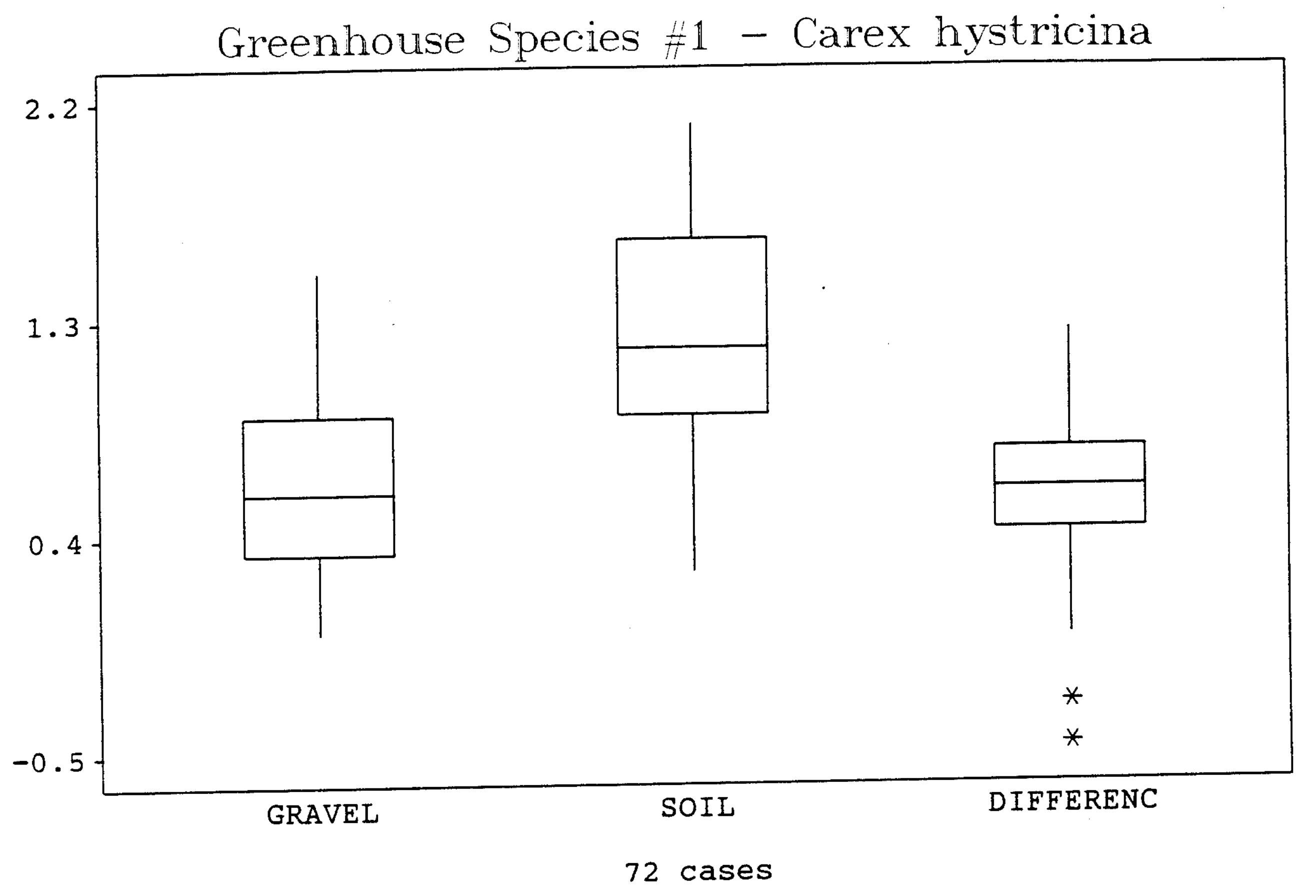
Appendix G -- Example of Equal (not significantly different) Growth on Either Soil or Gravel Till per Modified Height Data on Species Planted form Seed - (Box and Whiskers Plot)



Appendix H -- Example of Sensitivity to Substrate Type (Grew Differently on Soil vs Till) per Modified Height Data from Species Planted from Greenhouse Stock (Scatterplot)



Appendix H -- Example of Sensitivity to Substrate Type (Grew Differently on Soil vs Till) per Modified Height Data from Species Planted from <u>Greenhouse</u> Stock (Box and Whiskers Plot)



Appendix I – Water Chemistry Data (Organized by Sample Date)

Trial #	Sample Date	Lower (1) or Upper (2)	Gravel (1) or Soil (2)(0=well)	Plot #	PO_4^{-3} [mg/l]	pH	Nitrate [mg/l]	Iron (Total Fe mg/L)	Alkalinity [mg/l $CaCO_3$]	Total Hardness (mg/L)	Ca (mg/L)	Mg (mg/L)	Ammonium Ion (mg/L)	Sulfate [mg/l]
1	10-Jul-95	1	1	1	M	M	M	M	M	M	M	M	M	M
1	10-Jul-95	2	1	1	0.00	7.5	M	M	M	M	M	M	M	M
1	10-Jul-95	1	1	2	0.00	7.5	M	M	M	M	M	M	M	M
1	10-Jul-95	2	1	2	0.00	7.5	M	M	M	M	M	M	M	M
1	10-Jul-95	1	1	3	0.00	7.5	M	M	M	M	M	M	M	M
1	10-Jul-95	2	1	3	0.00	7.5	M	M	M	M	M	M	M	M
1	10-Jul-95	1	1	4	0.00	7.5	M	M	M	M	M	M	M	M
1	10-Jul-95	2	1	4	0.08	7.5	M	M	M	M	M	M	M	M
1	10-Jul-95	Weir	1	Weir	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	1	2	1	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	2	2	1	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	1	2	2	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	2	2	2	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	1	2	3	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	2	2	3	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	1	2	4	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	2	2	4	0.08	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	Weir	2	Weir	0.00	7.5	M	M	M	M	M	M	M	M
1	9-Jul-95	Well	0	Well	0.36	7.5	M	M	M	M	M	M	M	M
2	24-Jul-95	1	1	1	M	M	M	M	M	M	M	M	M	M
2	24-Jul-95	2	1	1	0.00	7.5	0.352	0.06	43	204	102	102	M	51
2	24-Jul-95	1	1	2	0.00	7.5	0.264	0.06	49	221	153	68	M	40
2	24-Jul-95	2	1	2	0.00	7.5	0.264	0.05	44	221	204	17	M	41
2	24-Jul-95	1	1	3	0.00	7.5	0.264	0.12	46	187	51	136	M	35
2	24-Jul-95	2	1	3	0.00	7.5	0.616	0.02	38	221	85	136	M	43
2	24-Jul-95	1	1	4	0.00	7.5	0.000	0.04	41	187	136	51	M	51
2	24-Jul-95	2	1	4	0.00	7.5	0.000	0.03	47	187	170	17	M	56
2	24-Jul-95	Weir	1	Weir	0.00	7.5	0.880	0.02	26	255	102	153	M	M
2	24-Jul-95	1	2	1	0.00	7.5	0.000	0.04	47	187	119	68	M	55
2	24-Jul-95	2	2	1	0.00	7.5	0.352	0.04	35	272	68	204	M	60
2	24-Jul-95	1	2	2	0.00	7.5	0.000	0.04	48	221	119	102	M	M
2	24-Jul-95	2	2	2	0.00	7.5	0.220	0.05	45	255	136	119	M	53
2	24-Jul-95	1	2	3	0.00	7.5	0.000	0.03	59	221	170	51	M	55
2	24-Jul-95	2	2	3	0.00	7.5	0.352	0.03	38	272	136	136	M	37
2	24-Jul-95	1	2	4	0.00	7.5	0.264	0.20	45	221	68	153	M	42
2	24-Jul-95	2	2	4	0.00	7.5	0.528	0.05	40	204	68	136	M	52
2	24-Jul-95	Weir	2	Weir	0.00	7.5	1.496	0.02	40	340	68	272	M	M
2	24-Jul-95	Well	0	Well	0.00	7.5	3.168	0.02	43	306	85	221	M	M
3	9-Aug-95	1	1	1	M	M	M	M	M	M	M	M	M	M
3	9-Aug-95	2	1	1	0.00	7.5	0.000	0.06	34	204	153	51	0.26	60
3	9-Aug-95	1	1	2	0.00	7.5	0.000	0.04	33	170	102	68	0.39	37
3	9-Aug-95	2	1	2	0.00	7.5	0.000	0.04	31	136	85	51	0.65	40
3	9-Aug-95	1	1	3	0.00	7.5	0.264	0.10	30	187	119	68	0.39	43
3	9-Aug-95	2	1	3	0.00	7.5	0.264	0.20	30	187	102	85	0.39	41
3	9-Aug-95	1	1	4	0.00	7.5	0.264	0.10	35	187	68	119	0.33	50
3	9-Aug-95	2	1	4	0.00	7.5	0.264	0.05	36	187	51	136	0.33	49
3	9-Aug-95	Weir	1	Weir	0.00	7.5	0.616	0.08	31	238	170	68	0.52	M
3	9-Aug-95	1	2	1	0.00	7.5	0.000	0.00	47	187	102	85	0.33	54
3	9-Aug-95	2	2	1	0.00	7.5	0.000	0.05	38	204	119	85	0.33	52
3	9-Aug-95	1	2	2	0.00	7.5	0.000	0.08	42	221	221	0	0.26	53
3	9-Aug-95	2	2	2	0.00	7.5	0.000	0.00	58	221	119	102	0.33	75
3	9-Aug-95	1	2	3	0.00	7.5	0.264	0.00	49	204	136	68	0.39	47
3	9-Aug-95	2	2	3	0.00	7.5	0.616	0.00	50	204	136	68	0.39	50
3	9-Aug-95	1	2	4	0.00	7.5	0.264	0.04	33	187	153	34	0.39	45
3	9-Aug-95	2	2	4	0.00	7.5	1.496	0.00	45	221	68	153	0.39	50
3	9-Aug-95	Weir	2	Weir	0.16	7.5	1.584	0.02	33	204	170	34	0.39	M
3	9-Aug-95	Well	0	Well	0.00	7.5	2.288	0.02	47	221	119	102	0.39	M

Legend: M = Missing Data Point (in Sample 1 we ran out of water samples before we finished the test kit analysis

Column #3: 1 = 6"-12" Below Surface= Below Root Zone; 0 = 0"-6" Below Surface = Root Zone

Column #4: 1 = Gravel Substrate; 2 = Soil Substrate

Column #5: Plot # 1-4, Weir = Sample taken from an Exit Weir; Well = Sample taken at well (main water source)

Appendix J -- Upper level (0-6" below the surface) water sample data.

Trial #	Plot #	Sample Date	PO_4^{-3} – SOIL	PO_4^{-3} – GRAVEL	PO_4^{-3} – DIFFERENCE	pH – SOIL	pH – GRAVEL	pH – DIFFERENCE	Nitrate – SOIL	Nitrate – GRAVEL	Nitrate – DIFFERENCE	Iron (mg/L) – SOIL	Iron (mg/L) – GRAVEL	Iron(mg/L) – DIFFERENCE	Alkalinity – SOIL	Alkalinity – GRAVEL	Alkalinity – DIFFERENCE	Total Hardness – SOIL	Total Hardness – GRAVEL	Total Hardness – DIFFERENCE	Ca^{2+} – SOIL	Ca^{2+} – GRAVEL	Ca^{2+} – DIFFERENCE	Mg^{2+} – SOIL	Mg^{2+} – GRAVEL	Mg^{2+} – DIFFERENCE	Ammonium ion – SOIL	Ammonium ion – GRAVEL	Ammonium ion – DIFFERENCE	Sulfate – SOIL	Sulfate – GRAVEL	Sulfate – DIFFERENCE
1	1	10-Jul-95	0.00	0.00	0.00	7.5	7.5	0	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
1	2	10-Jul-95	0.00	0.00	0.00	7.5	7.5	0	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
1	3	10-Jul-95	0.00	0.00	0.00	7.5	7.5	0	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
1	4	10-Jul-95	0.08	0.08	0.00	7.5	7.5	0	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
2	1	24-Jul-95	0.00	0.00	0.00	7.5	7.5	0	0.352	0.352	0.00	0.06	0.04	0.02	43	35	8	204	272	-68	102	204	-102	102	68	34	M	M	M	51	60	-9
2	2	24-Jul-95	0.00	0.00	0.00	7.5	7.5	0	0.264	0.220	0.044	0.05	0.05	0.00	44	45	-1	221	255	-34	17	119	-102	204	136	68	M	M	M	41	53	-12
2	3	24-Jul-95	0.00	0.00	0.00	7.5	7.5	0	0.616	0.352	0.264	0.02	0.03	-0.01	38	38	0	221	272	-51	136	136	0	85	136	-51	M	M	M	43	37	6
2	4	24-Jul-95	0.00	0.00	0.00	7.5	7.5	0	0.000	0.528	-0.528	0.03	0.05	-0.02	47	40	7	187	204	-17	17	136	-119	170	68	102	M	M	M	56	52	4
3	1	9-Aug-95	0.00	0.00	0.00	7.5	7.5	0	0.000	0.000	0.00	0.06	0.05	0.01	34	38	-4	204	204	0	51	85	-34	153	119	34	0.33	0.26	0.065	60	52	8
3	2	9-Aug-95	0.00	0.00	0.00	7.5	7.5	0	0.000	0.000	0.000	0.04	0.00	0.04	31	58	-27	136	221	-85	51	102	-51	85	119	-34	0.33	0.65	-0.33	40	75	-35
3	3	9-Aug-95	0.00	0.00	0.00	7.5	7.5	0	0.264	0.616	-0.352	0.20	0.00	0.20	30	50	-20	187	204	-17	85	68	17	102	136	-34	0.39	0.39	0.00	41	50	-9
3	4	9-Aug-95	0.00	0.00	0.00	7.5	7.5	0	0.264	1.496	-1.232	0.05	0.00	0.05	36	45	-9	187	221	-34	136	153	-17	51	68	-17	0.39	0.33	0.07	49	50	-1

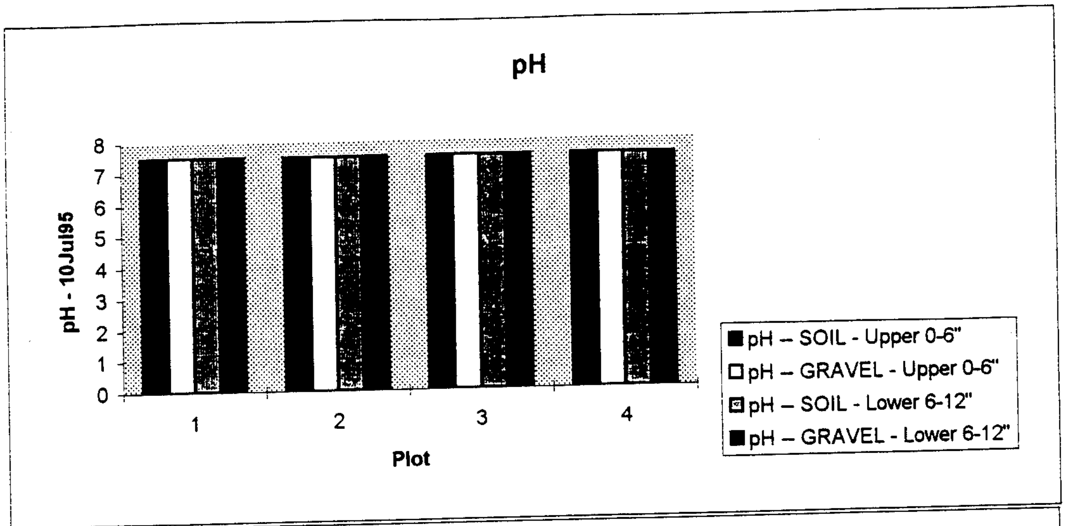
* M = Missing Data Point & Zero (0 or 0.00 or 0.000) = Sample Analyzed but Chemistry Parameter Is Below Detection Limit

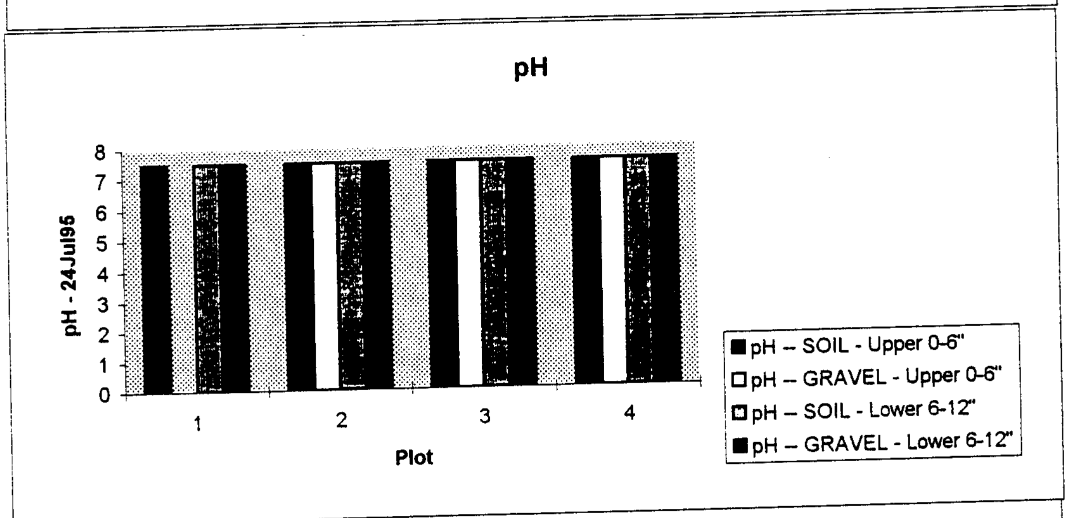
Appendix K -- Lower level (6-12" below the surface) water sample data.

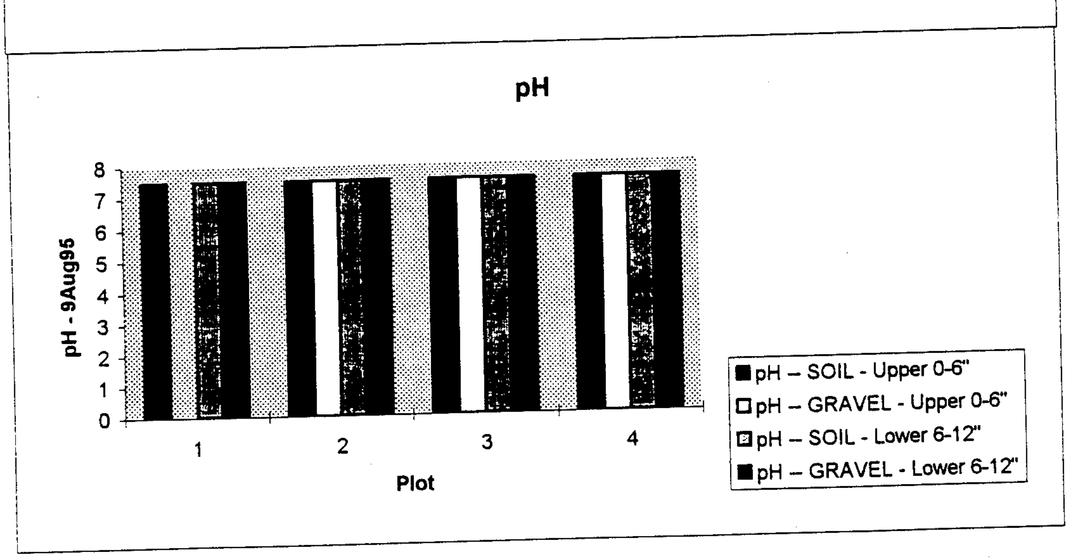
Trial #	Plot #	Sample Date	PO_4^{-3} – SOIL	PO_4^{-3} – GRAVEL	PO_4^{-3} – DIFFERENCE	pH – SOIL	pH – GRAVEL	pH – DIFFERENCE	Nitrate – SOIL	Nitrate – GRAVEL	Nitrate – DIFFERENCE	Iron (mg/L) – SOIL	Iron (mg/L) – GRAVEL	Iron(mg/L) – DIFFERENCE	Alkalinity – SOIL	Alkalinity – GRAVEL	Alkalinity – DIFFERENCE	Total Hardness – SOIL	Total Hardness – GRAVEL	Total Hardness – DIFFERENCE	Ca^{2+} – SOIL	Ca^{2+} – GRAVEL	Ca^{2+} – DIFFERENCE	Mg^{2+} – SOIL	Mg^{2+} – GRAVEL	Mg^{2+} – DIFFERENCE	Ammonium ion – SOIL	Ammonium ion – GRAVEL	Ammonium ion – DIFFERENCE	Sulfate – SOIL	Sulfate – GRAVEL	Sulfate – DIFFERENCE
1	1	10-Jul-95	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
1	2	10-Jul-95	0.00	0.00	0.00	7.5	7.5	0	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
1	3	10-Jul-95	0.00	0.00	0.00	7.5	7.5	0	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
1	4	10-Jul-95	0.00	0.00	0.00	7.5	7.5	0	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
2	1	24-Jul-95	0.00	M	M	7.5	M	M	0.000	M	M	0.04	M	M	47	M	M	187	M	M	119	M	M	68	M	M	M	M	M	55	M	M
2	2	24-Jul-95	0.00	0.00	0.00	7.5	7.5	0	0.264	0.000	0.264	0.06	0.04	0.02	49	48	1	221	221	0	153	119	34	68	102	-34	M	M	M	40	M	M
2	3	24-Jul-95	0.00	0.00	0.00	7.5	7.5	0	0.264	0.000	0.264	0.12	0.03	0.09	46	59	-13	187	221	-34	51	170	-119	136	51	85	M	M	M	35	55	-20
2	4	24-Jul-95	0.00	0.00	0.00	7.5	7.5	0	0.000	0.264	-0.264	0.04	0.20	-0.16	41	45	-4	187	221	-34	136	68	68	51	153	-102	M	M	M	51	42	9
3	1	9-Aug-95	M	M	M	7.5	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	0.33	M	M	M	M	M
3	2	9-Aug-95	0.00	0.00	0.00	7.5	7.5	0	0.000	0.000	0.000	0.04	0.08	-0.04	33	42	-9	170	221	-51	102	221	-119	68	0	68	0.26	0.39	-0.13	37	53	-16
3	3	9-Aug-95	0.00	0.00	0.00	7.5	7.5	0	0.264	0.264	0.000	0.10	0.00	0.10	30	49	-19	187	204	-17	119	136	-17	68	68	0	0.39	0.39	0.00	43	47	-4
3	4	9-Aug-95	0.00	0.00	0.00	7.5	7.5	0	0.264	0.264	0.000	0.10	0.04	0.06	35	33	2	187	187	0	68	153	-85	119	34	85	0.39	0.33	0.07	50	45	5

* M = Missing Data Point & Zero (0 or 0.00 or 0.000) = Sample Analyzed but Chemistry Parameter Is Below Detection Limit

Appendix L -- Water Chemistry Comparisons Between Soil Depths and Substrates







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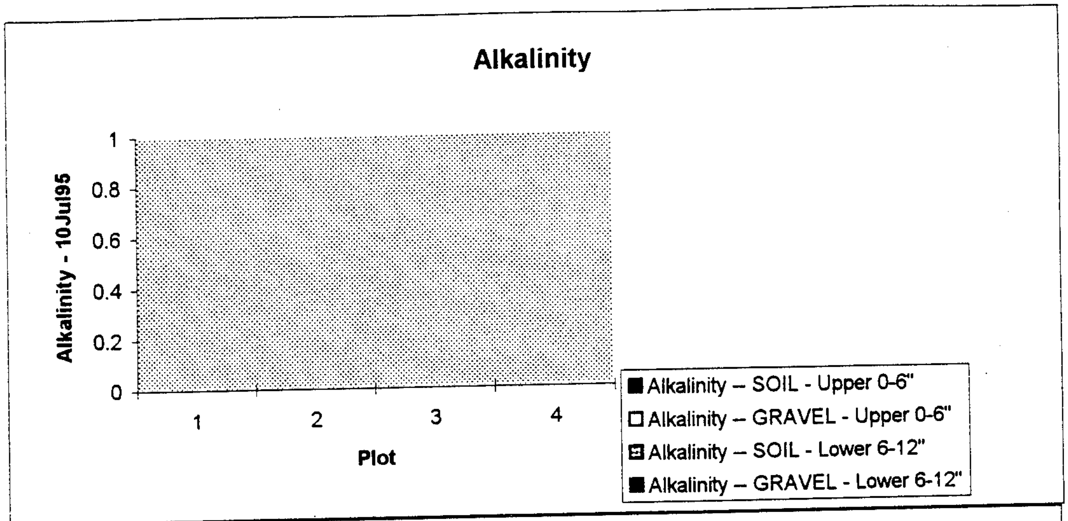

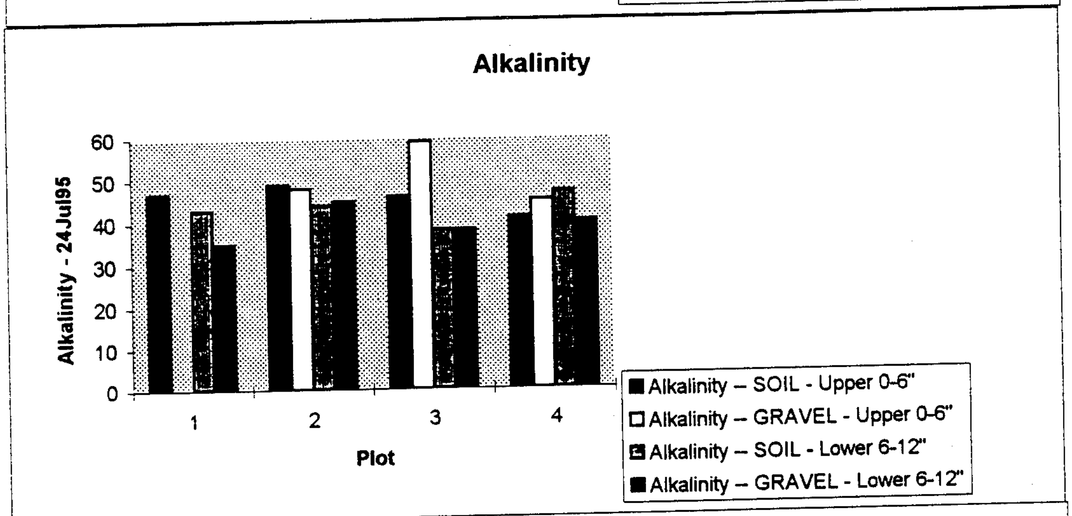

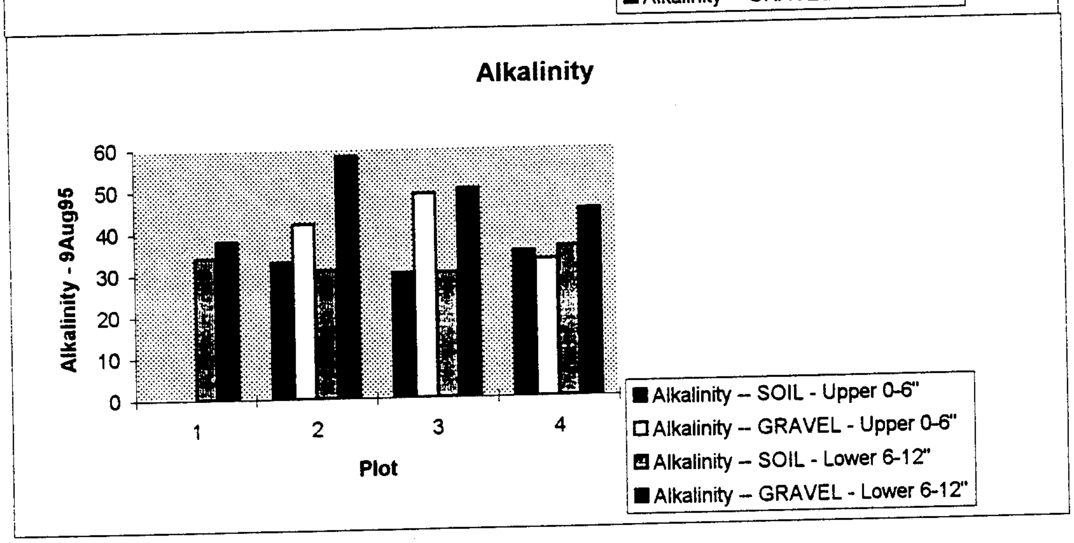

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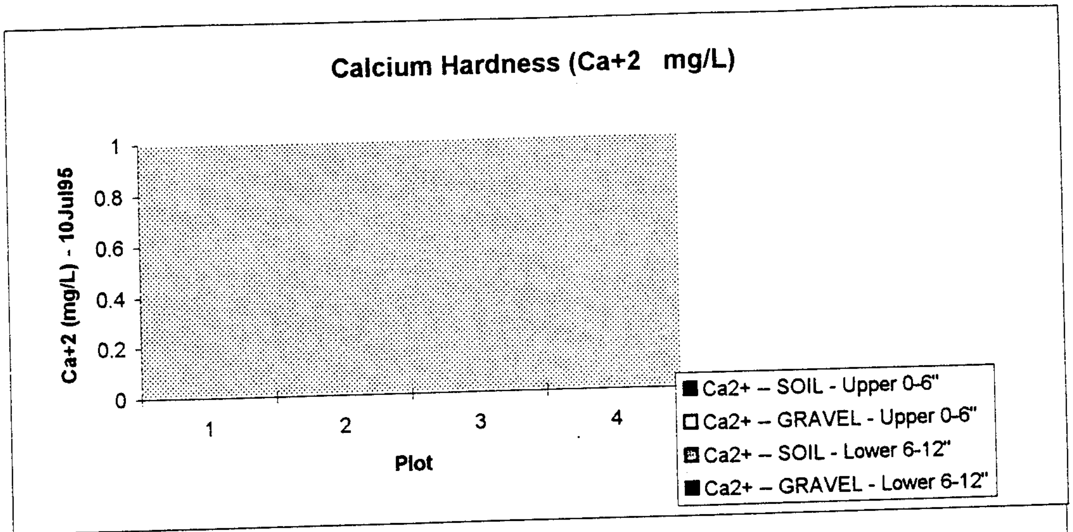

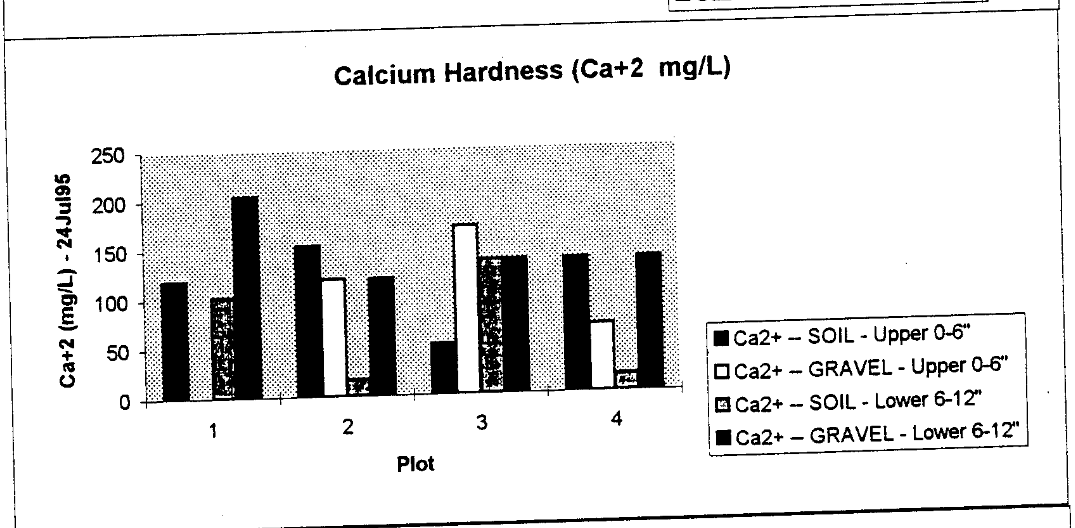

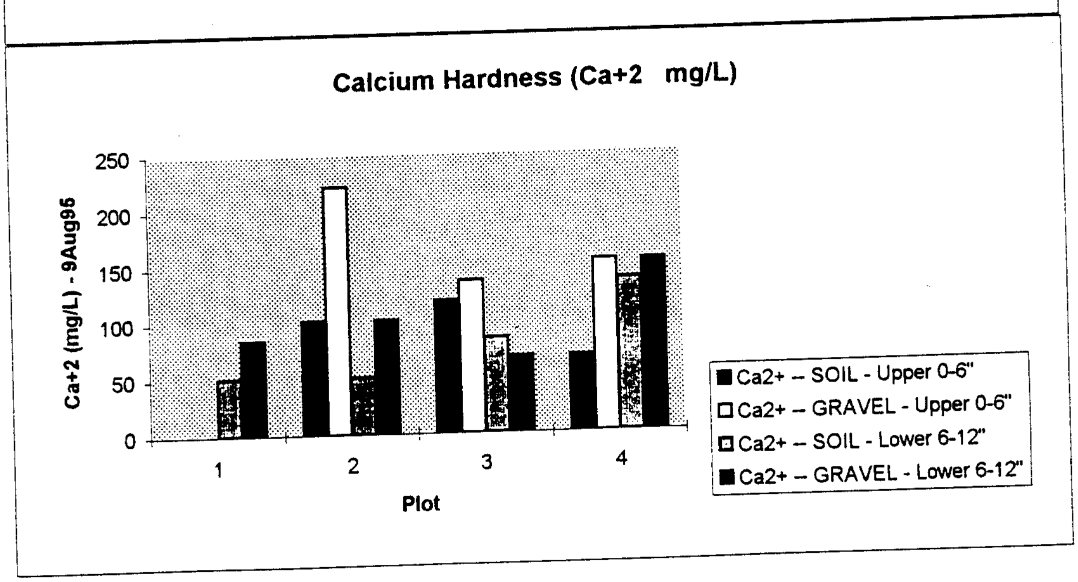

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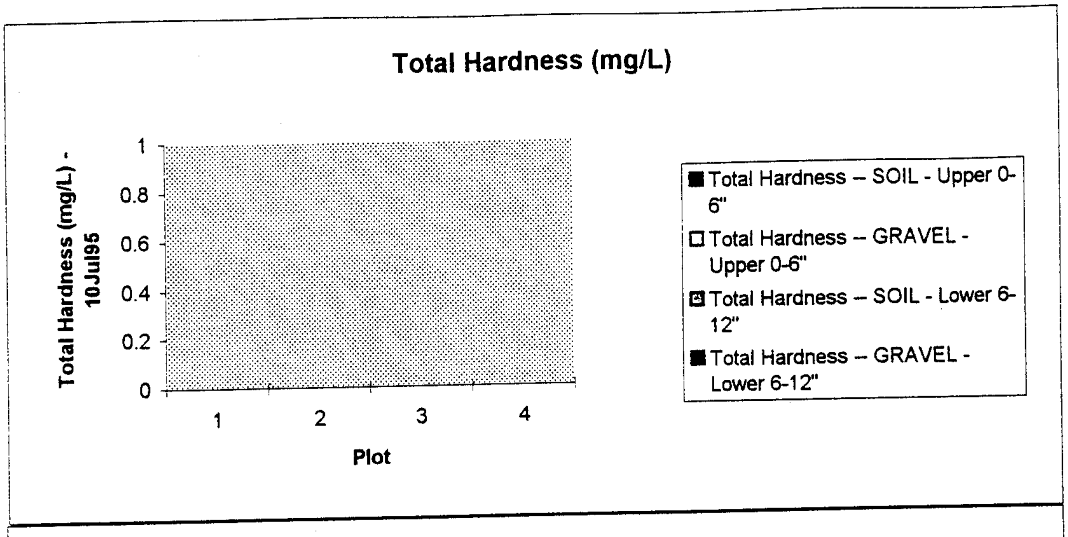

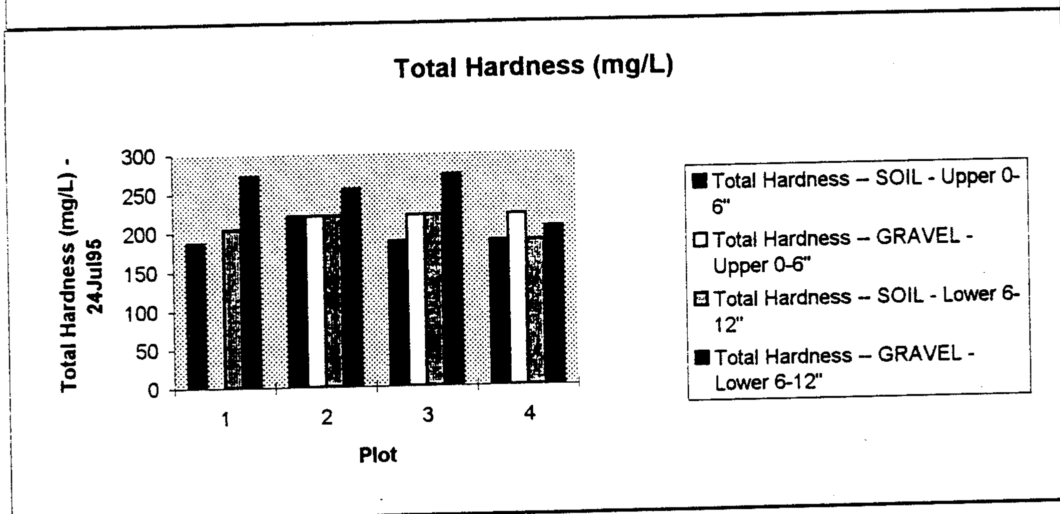

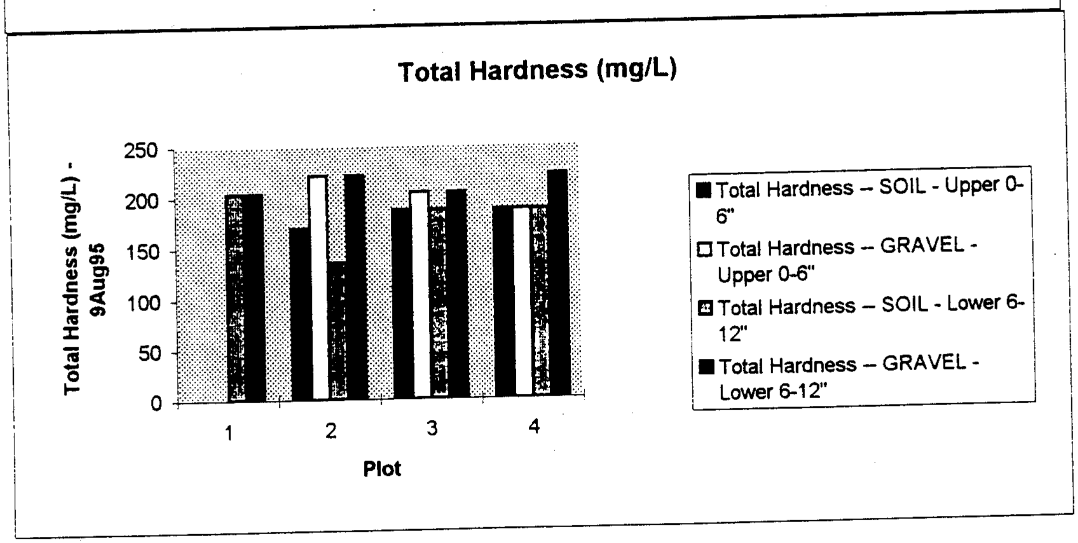

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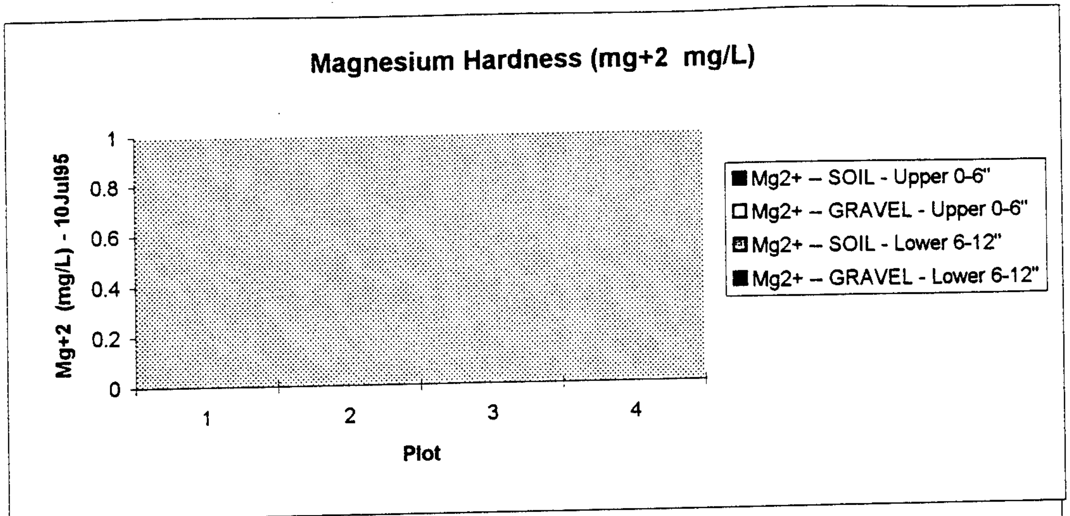

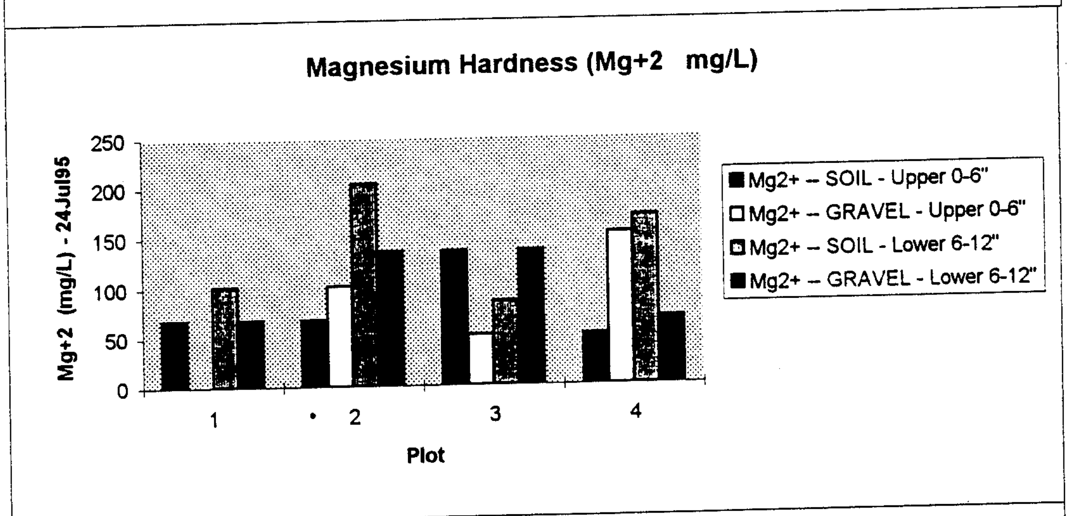

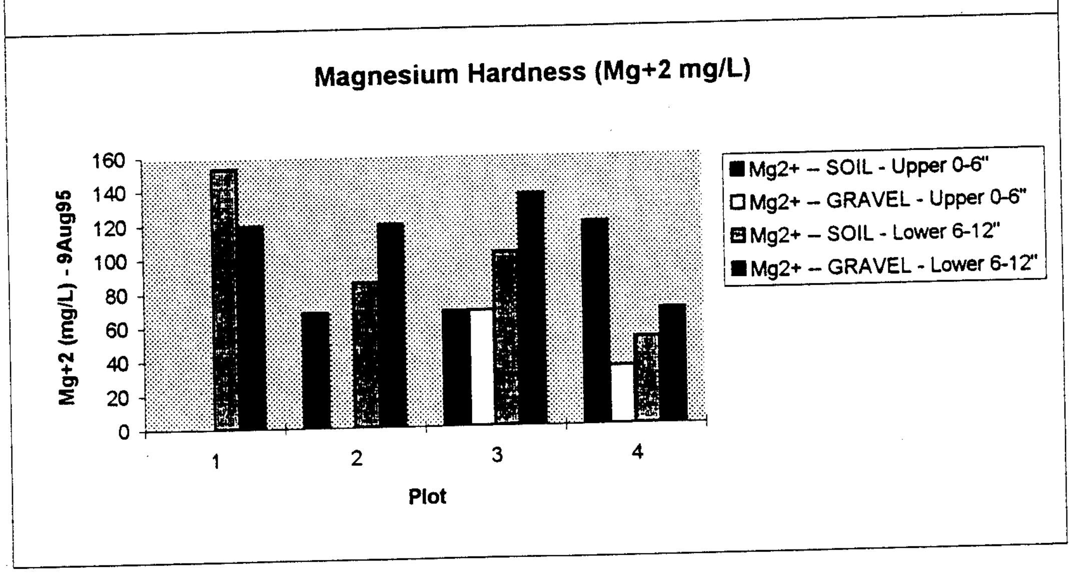

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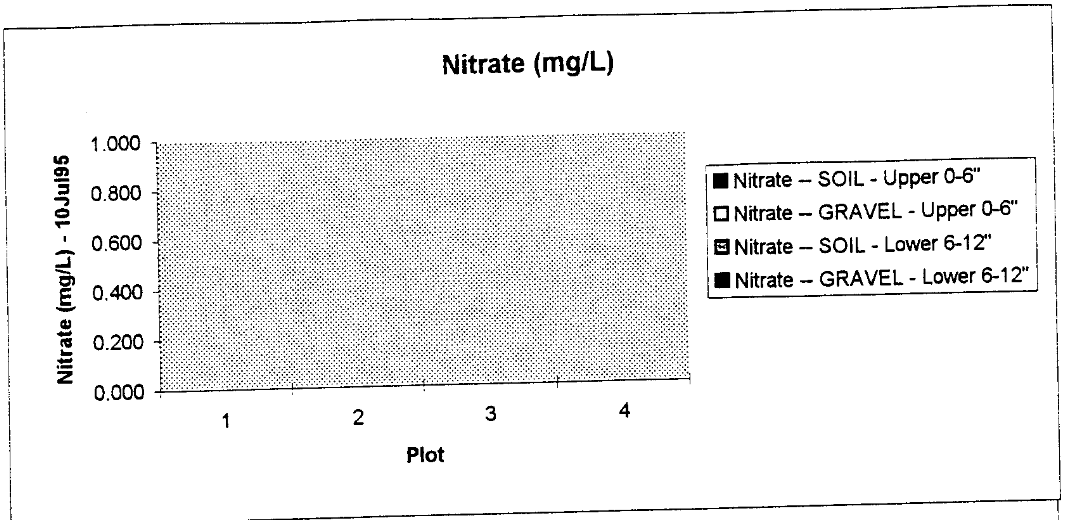

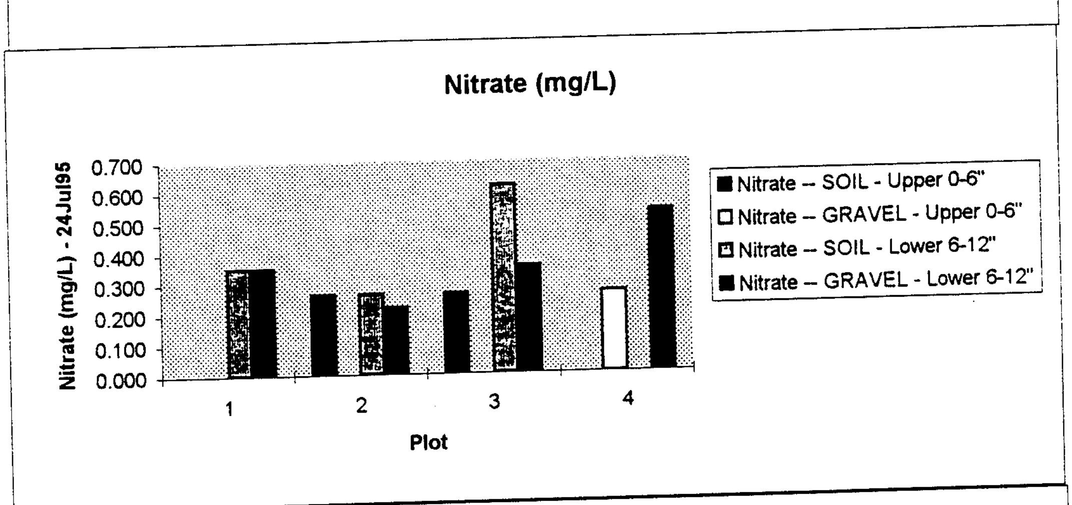

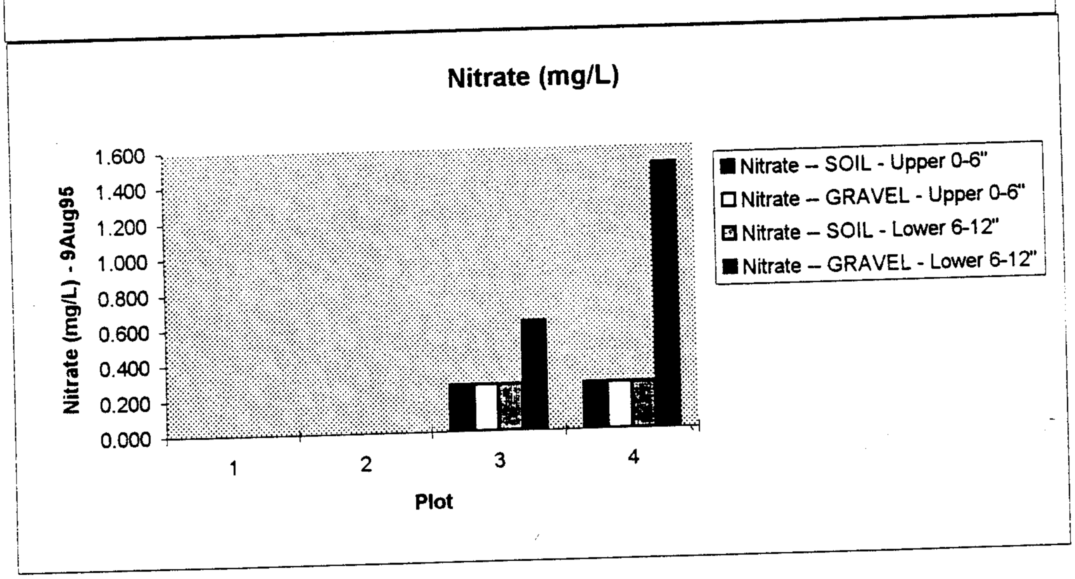

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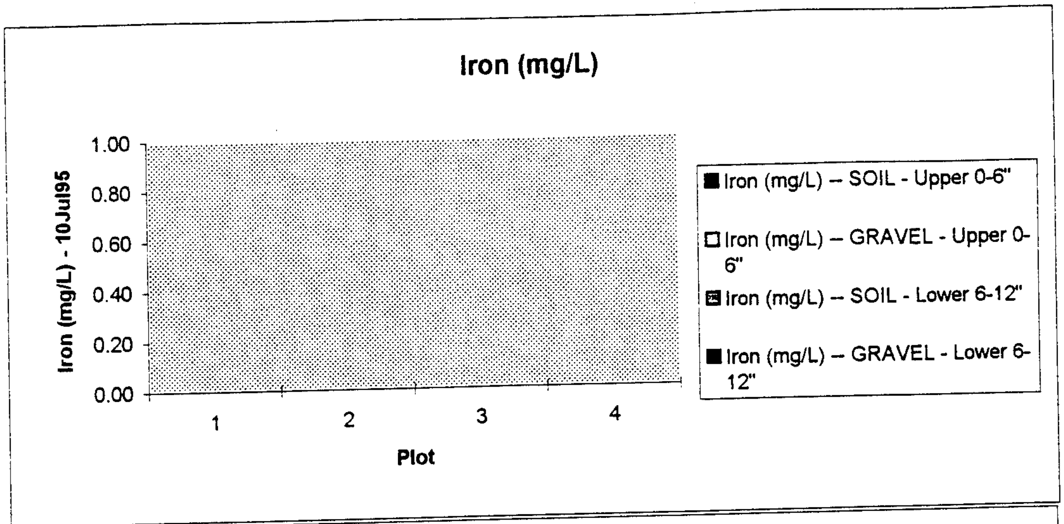

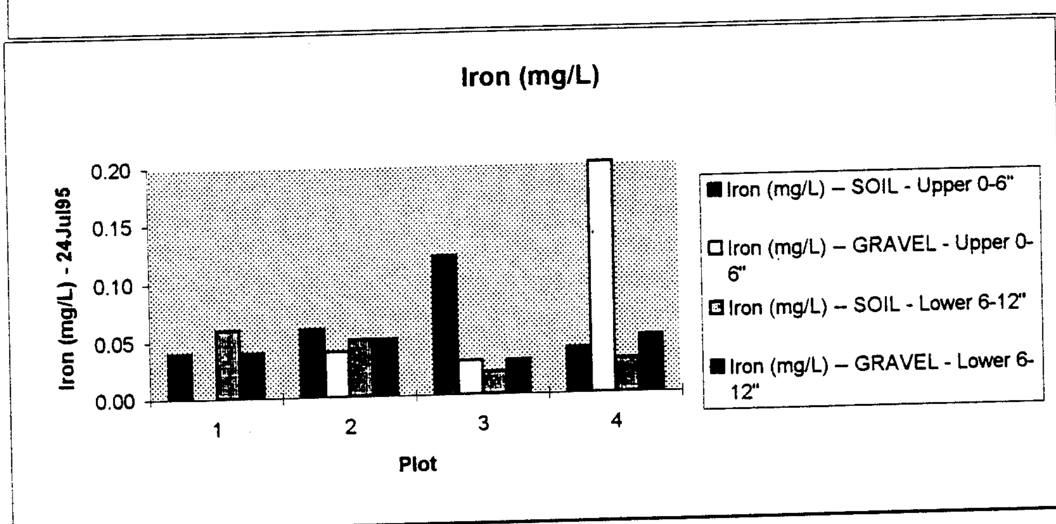

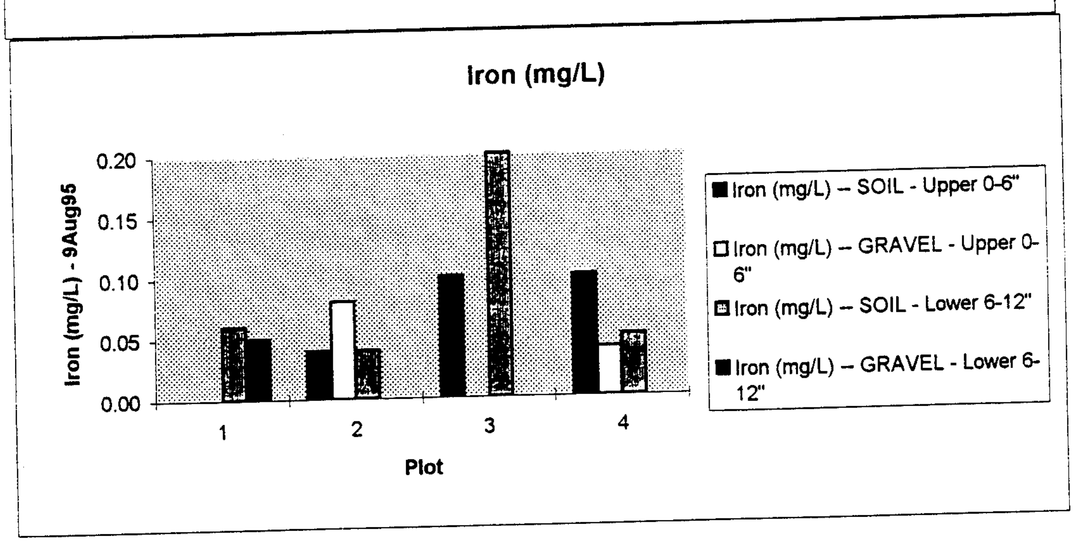

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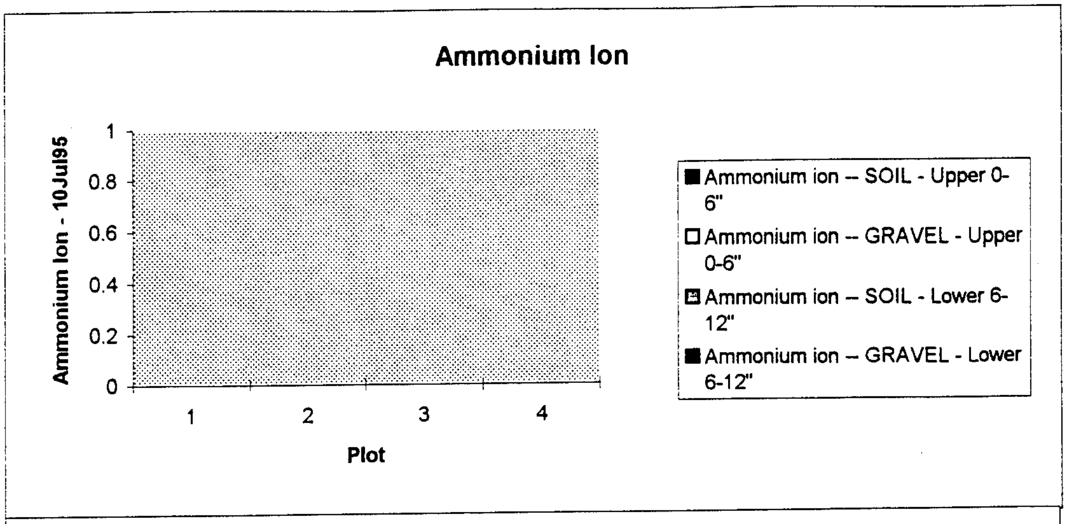

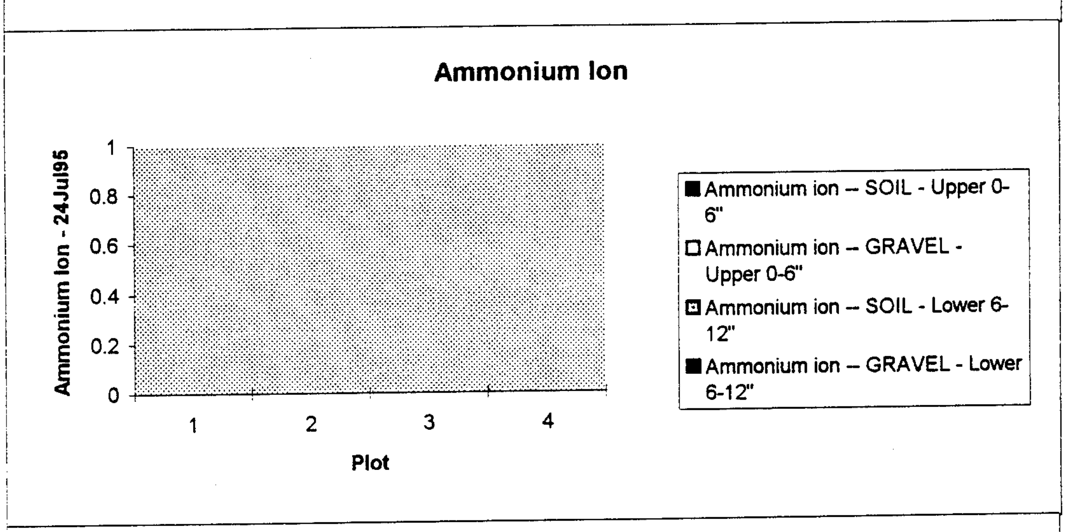

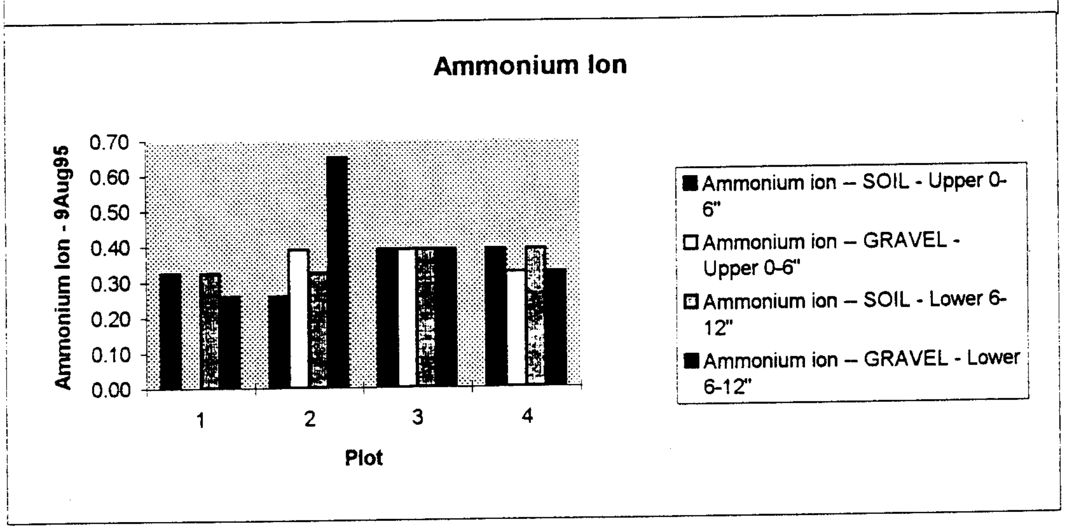

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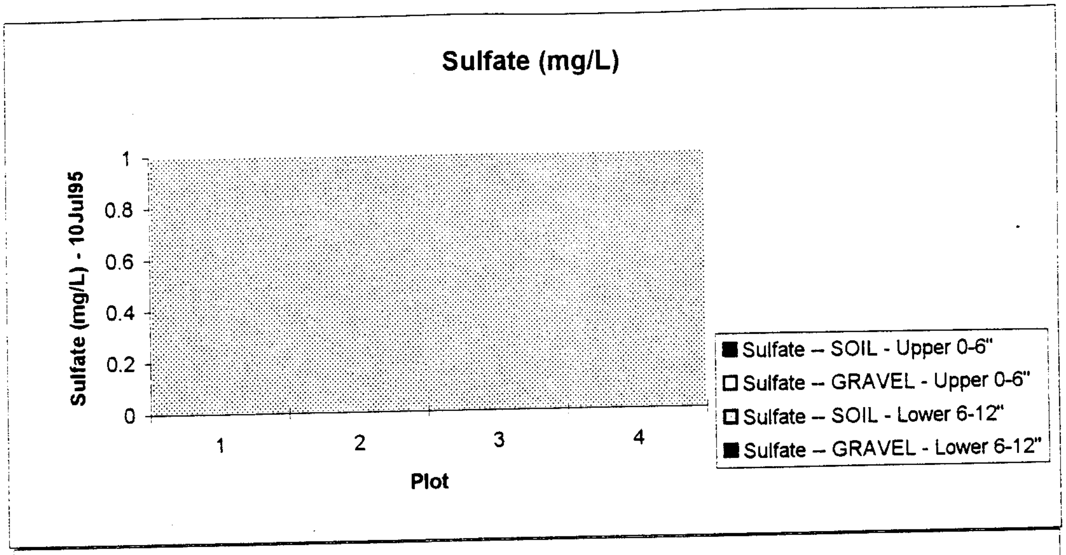
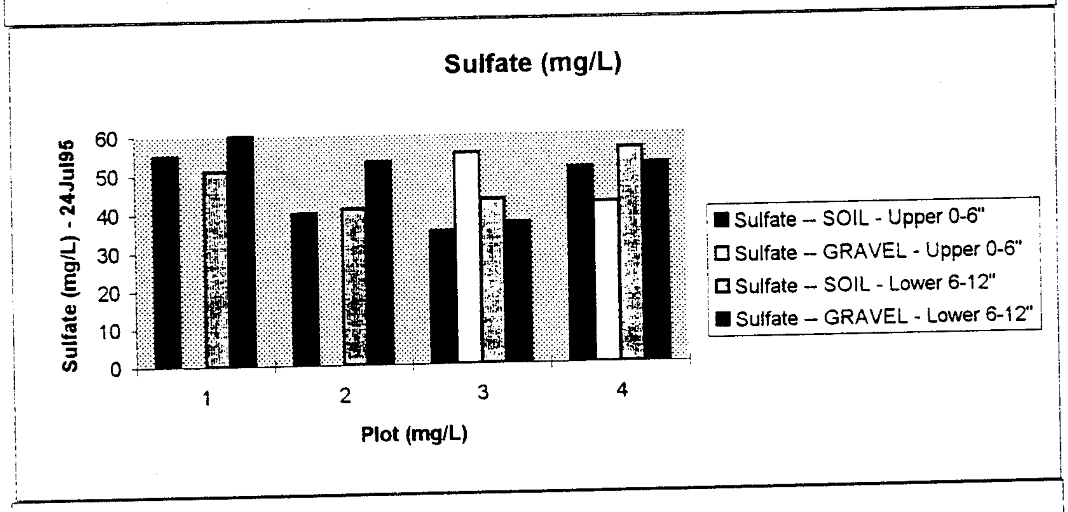
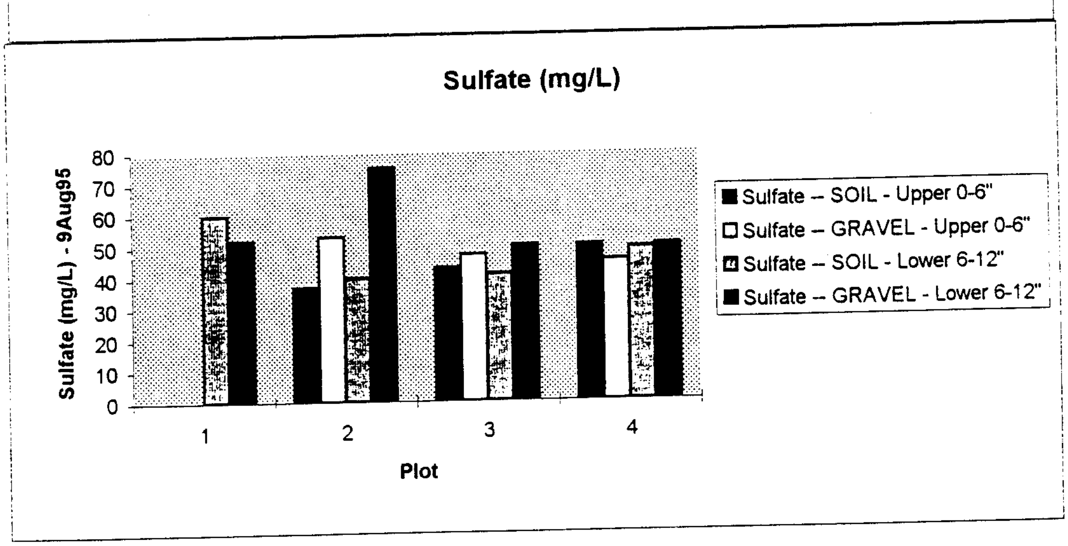
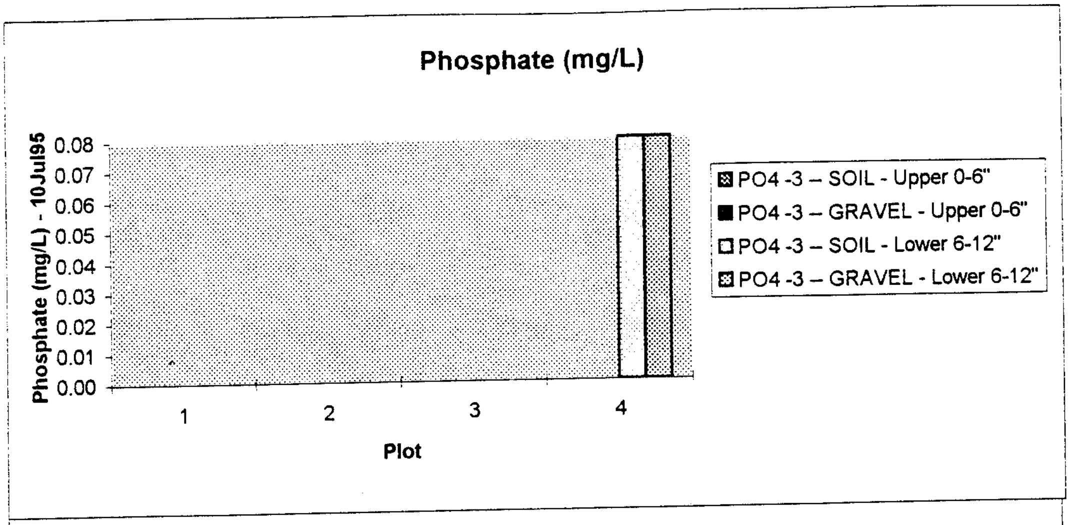
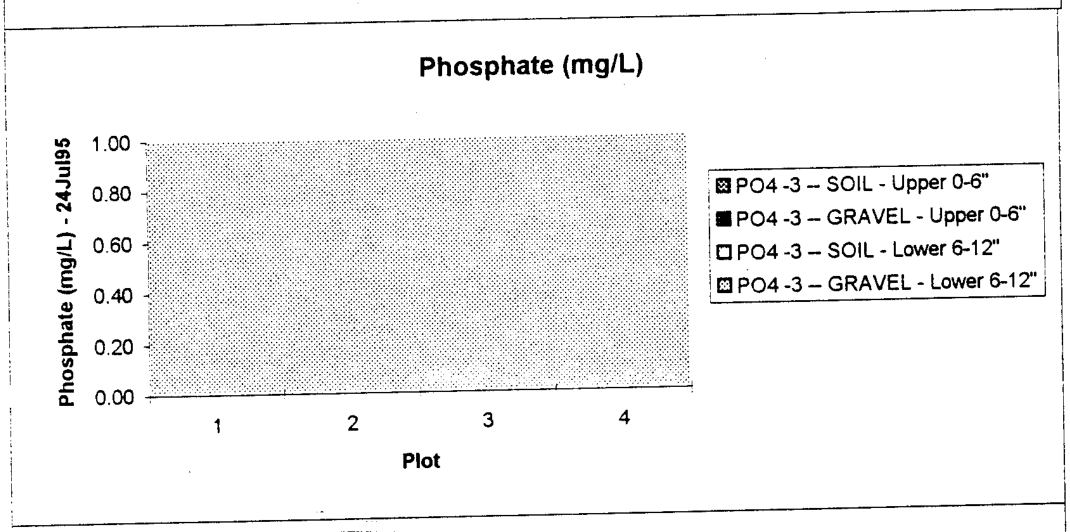


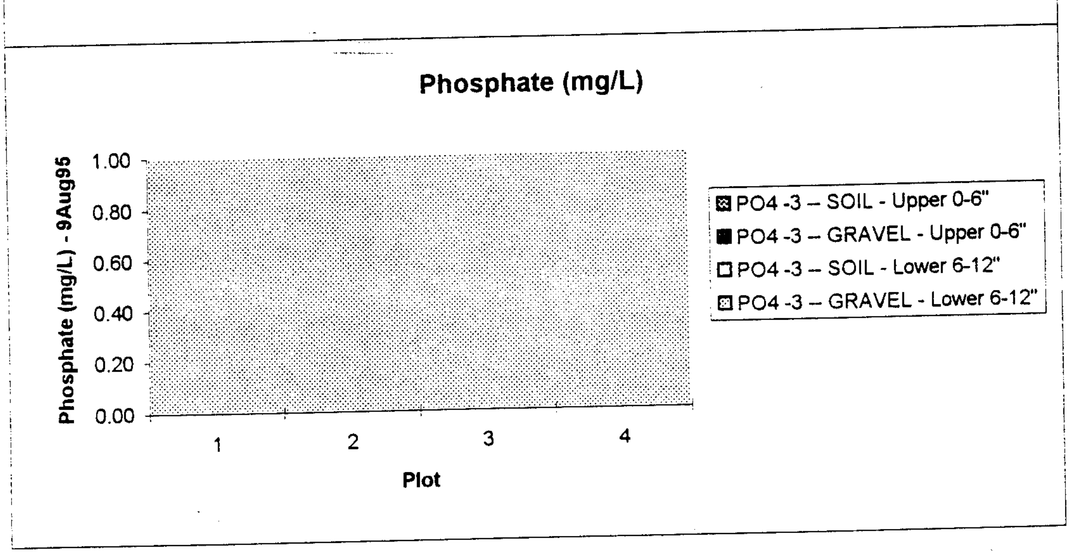




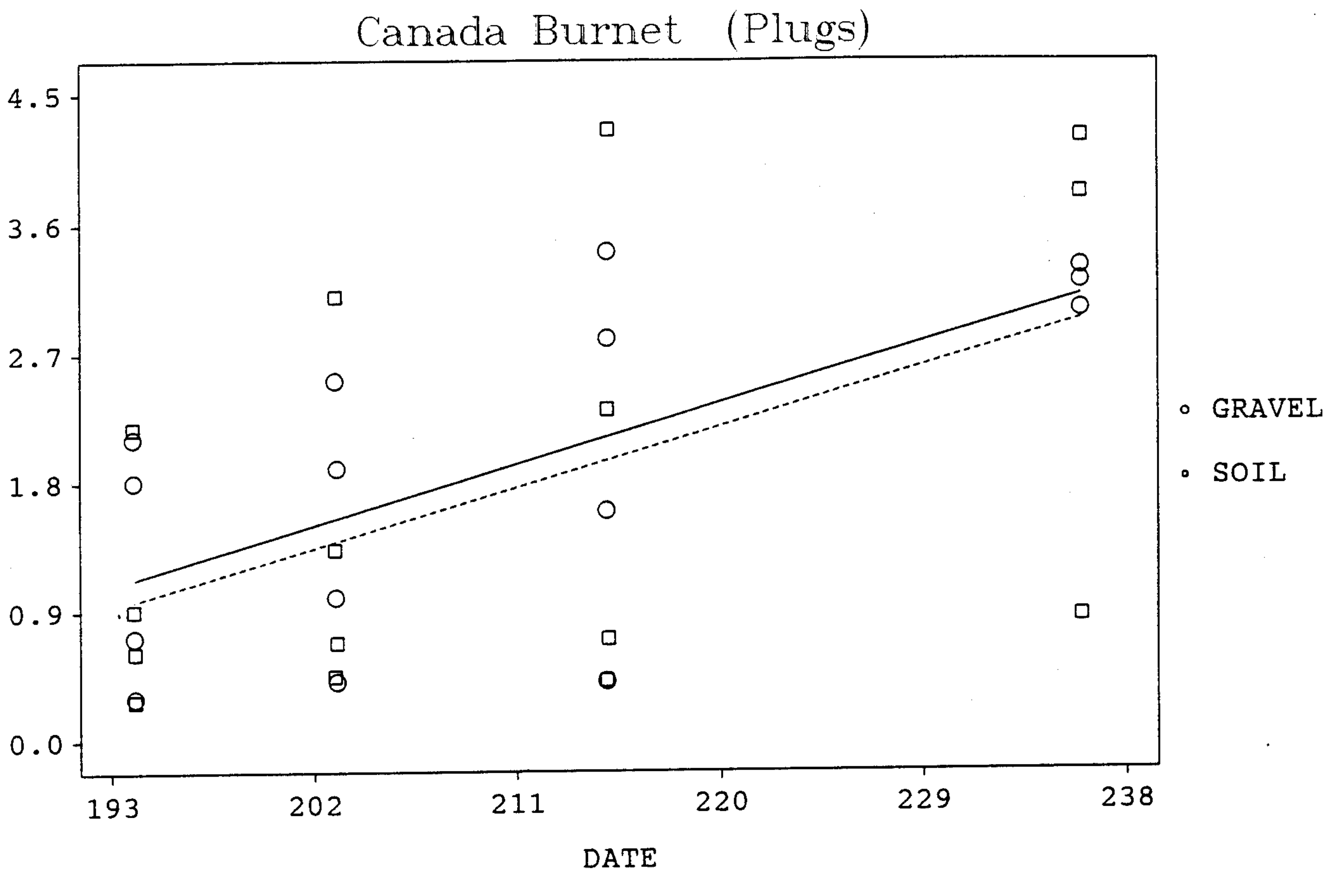
Appendix L -- Water Chemistry Comparisons Between Soil Depths and Substrates



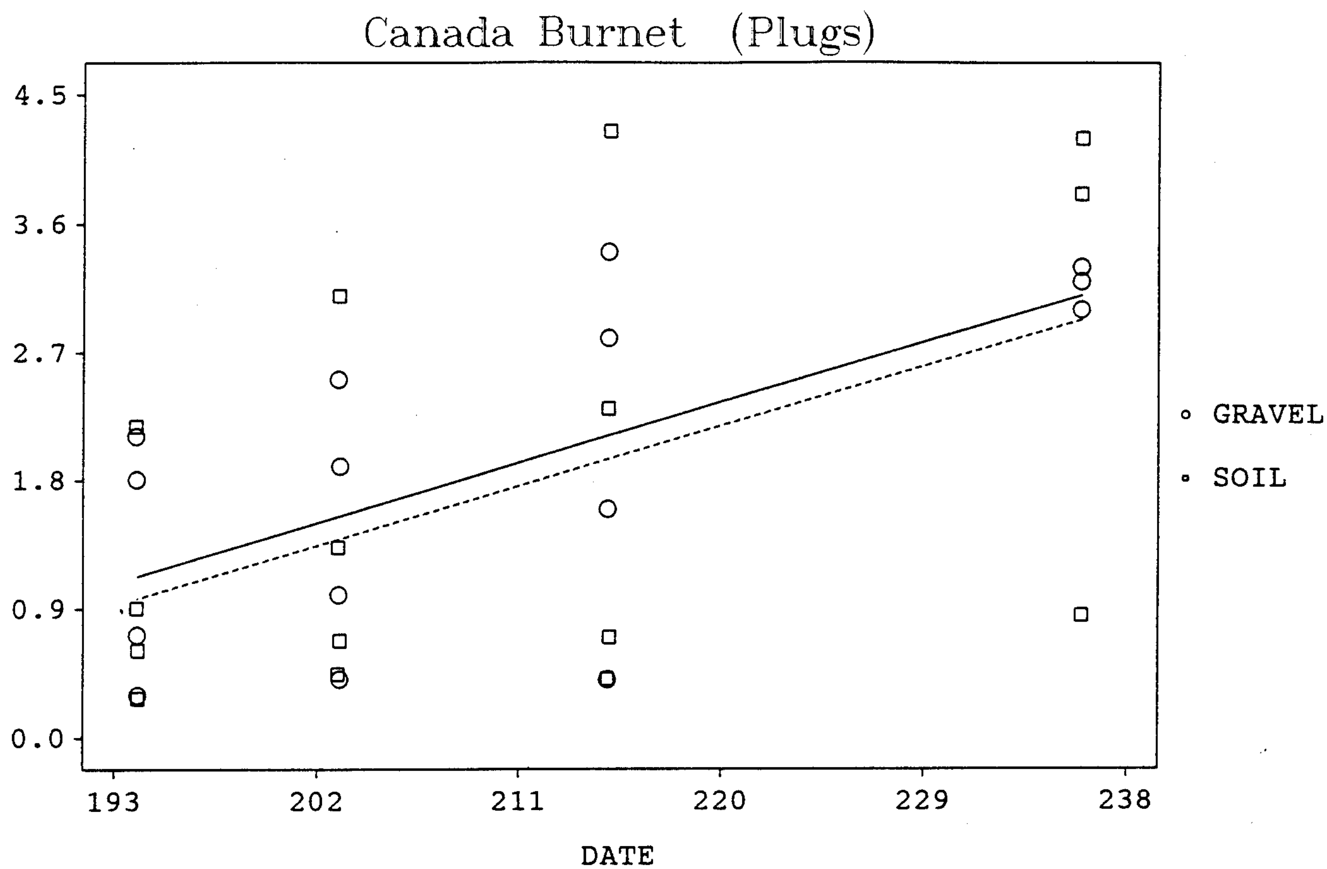




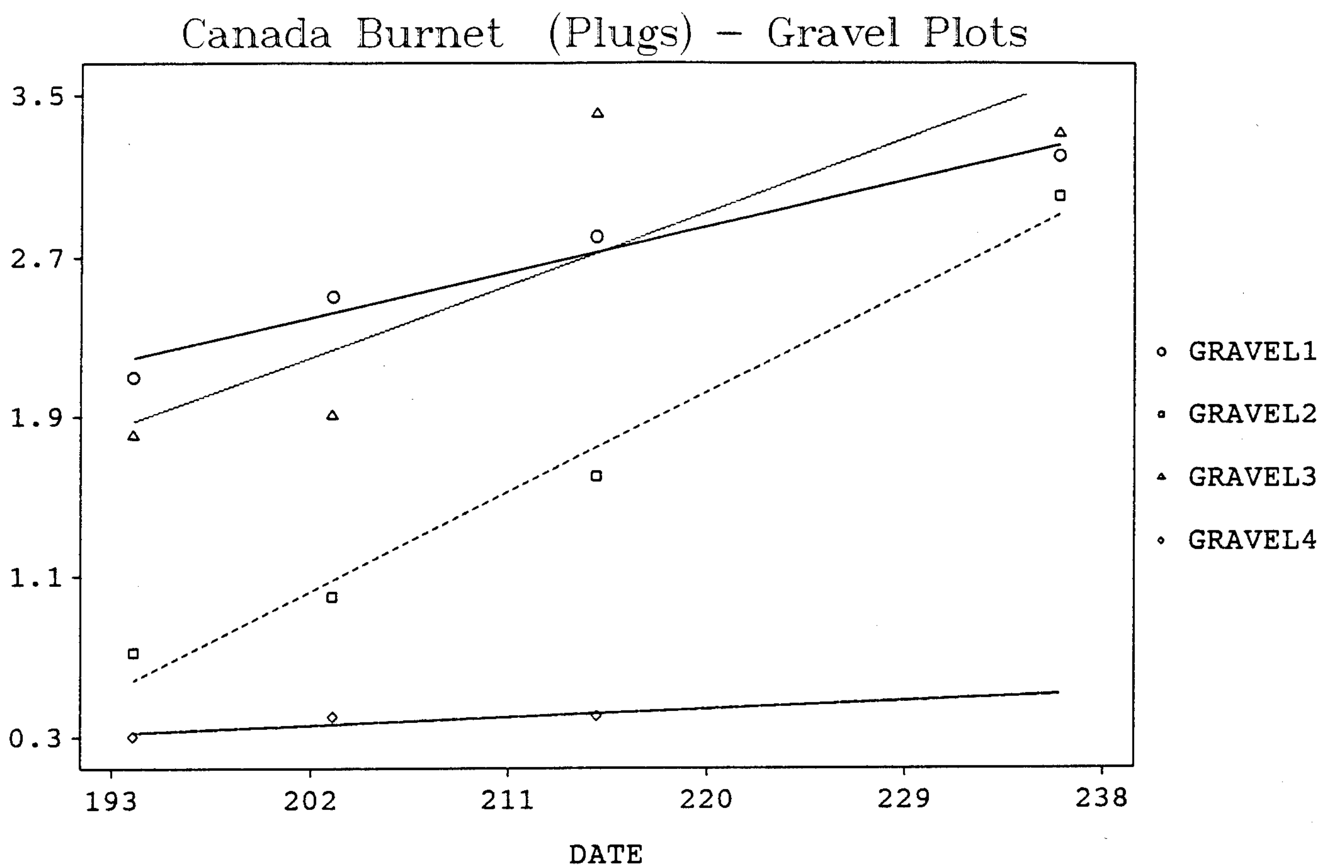
Appendix M -- Example of Natural Plug Species Maximum Height Data Scatterplots



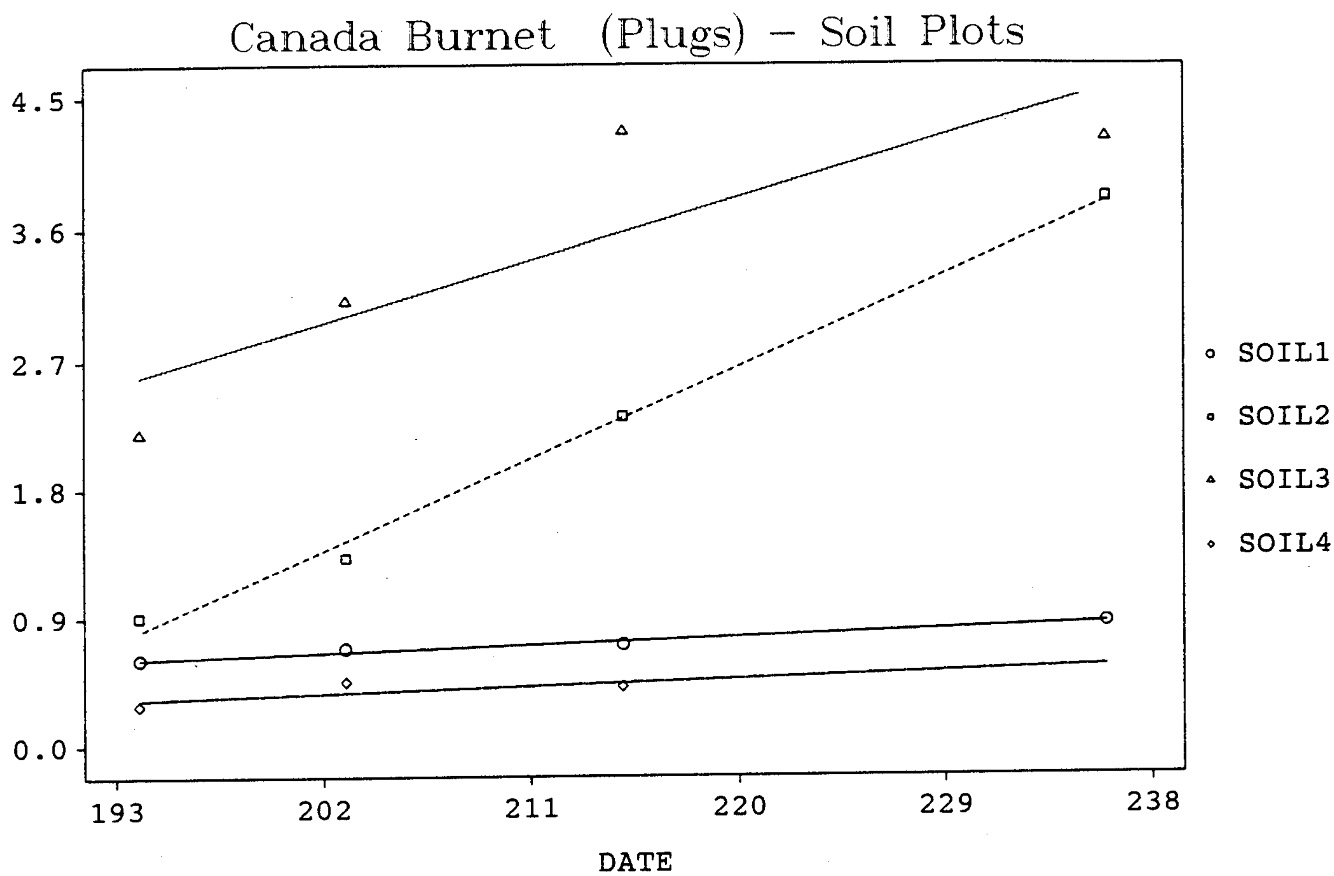
Appendix M -- Example of Natural Plug Species Maximum Height Data Scatterplots



Appendix M -- Example of Natural Plug Species Maximum Height Data Scatterplots

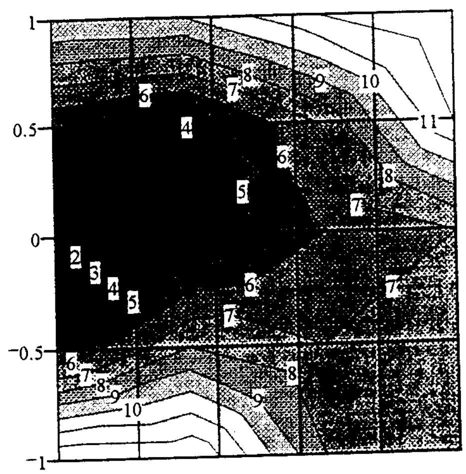


Appendix M -- Example of Natural Plug Species Maximum Height Data Scatterplots

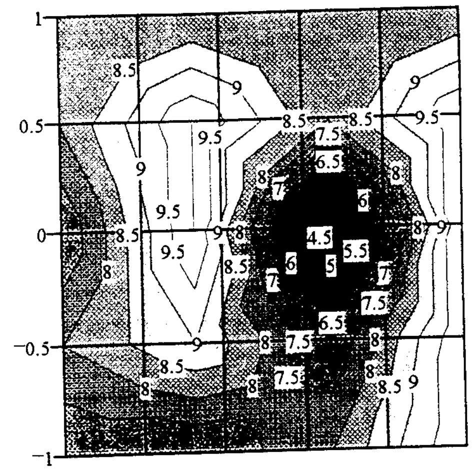


Appendix N -- Water/"Moisture" Contour Plots

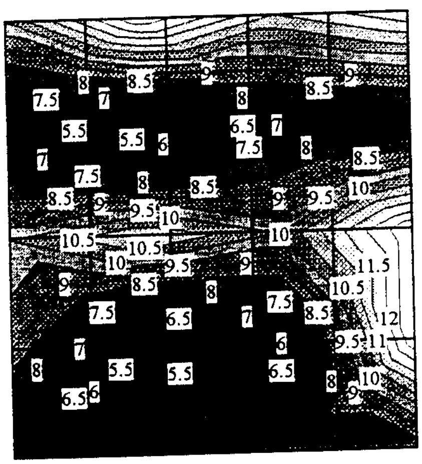
Gravel Substrate "Moisture" Contour Plots -- Seed Plots 1-4 (28 JUN 95)



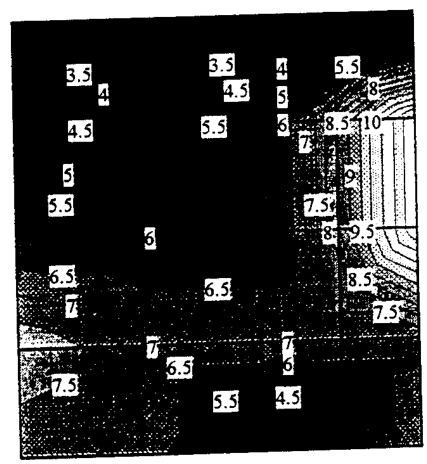
Gravelseedplot1



Gravelseedplot3



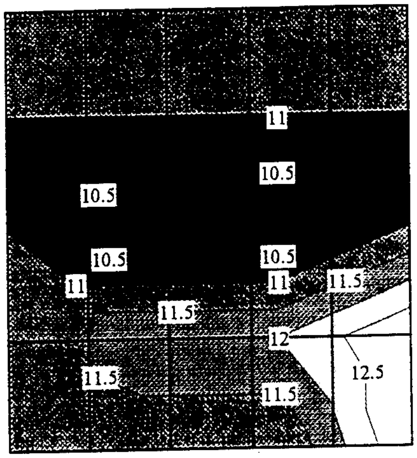
Gravelseedplot2



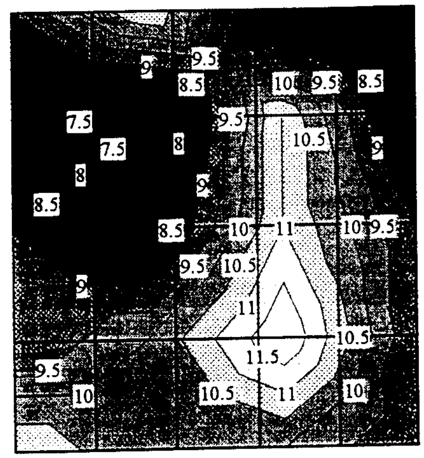
Gravelseedplot4

Appendix N -- Water/"Moisture" Contour Plots

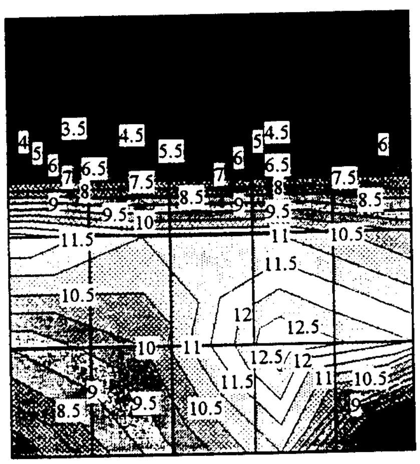
Gravel Substrate "Moisture" Contour Plots -- Greenhouse Plots 1-4 (28JUN95)



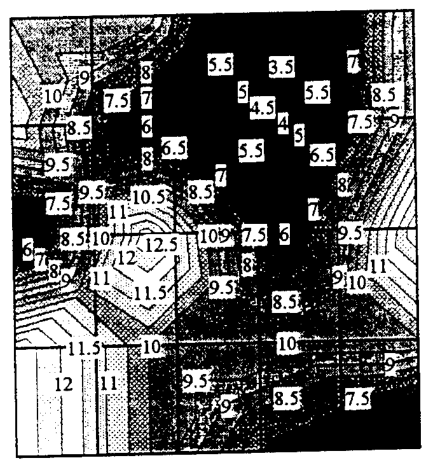
Gravelgreenhsplot1



Gravelgreenhsplot3



Gravelgreenhsplot2



Gravelgreenhsplot4

Appendix N -- Water/"Moisture" Contour Plots

$$\text{Gravelseedplot1} = \begin{bmatrix} 13 & 5 & 1 & 5 & 10 \\ 13 & 8 & 4 & 4 & 10 \\ 8 & 7 & 6 & 7 & 12 \\ 7 & 8 & 7 & 12 & 13 \end{bmatrix}$$

$$\text{Gravelgreenhsplot1} = \begin{bmatrix} 11 & 11 & 11 & 11 & 11 \\ 11 & 12 & 10 & 11 & 11 \\ 11 & 12 & 10 & 11 & 11 \\ 13 & 13 & 11 & 11 & 11 \end{bmatrix}$$

$$\text{Gravelseedplot2} = \begin{bmatrix} 6 & 9 & 10 & 6 & 10 \\ 5 & 5 & 11 & 5 & 13 \\ 8 & 6 & 10 & 7 & 11 \\ 8 & 13 & 13 & 7 & 12 \end{bmatrix}$$

$$\text{Gravelgreenhsplot2} = \begin{bmatrix} 7 & 9 & 12 & 3 & 3 \\ 9 & 10 & 11 & 4 & 4 \\ 11 & 13 & 11 & 4 & 4 \\ 3 & 12 & 10 & 5 & 4 \end{bmatrix}$$

$$\text{Gravelseedplot3} = \begin{bmatrix} 7 & 8 & 7 & 8 & 8 \\ 7 & 9 & 10 & 10 & 8 \\ 8 & 7 & 4 & 8 & 8 \\ 10 & 10 & 10 & 10 & 8 \end{bmatrix}$$

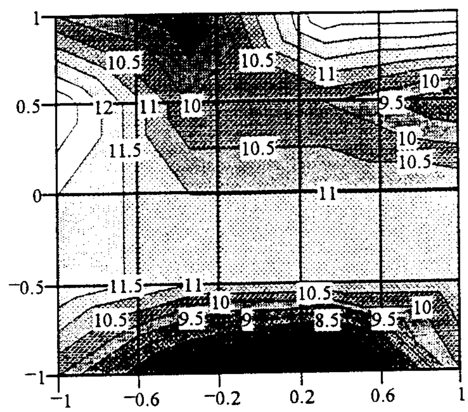
$$\text{Gravelgreenhsplot3} = \begin{bmatrix} 11 & 9 & 9 & 8 & 9 \\ 10 & 10 & 8 & 7 & 11 \\ 10 & 12 & 11 & 11 & 8 \\ 9 & 9 & 9 & 8 & 8 \end{bmatrix}$$

$$\text{Gravelseedplot4} = \begin{bmatrix} 7 & 8 & 6 & 4 & 3 \\ 7 & 7 & 6 & 5 & 2 \\ 2 & 7 & 6 & 6 & 2 \\ 7 & 7 & 12 & 12 & 2 \end{bmatrix}$$

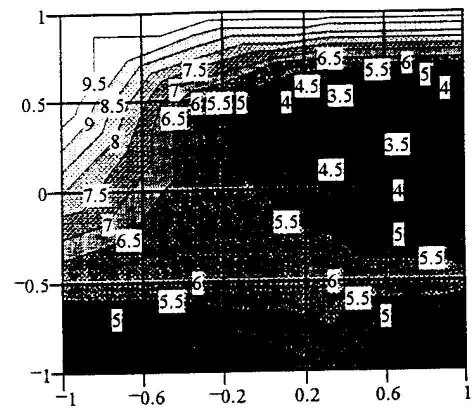
$$\text{Gravelgreenhsplot4} = \begin{bmatrix} 13 & 13 & 5 & 11 & 10 \\ 10 & 10 & 13 & 6 & 10 \\ 7 & 10 & 6 & 4 & 3 \\ 4 & 10 & 13 & 10 & 10 \end{bmatrix}$$

Appendix N -- Water/"Moisture" Contour Plots

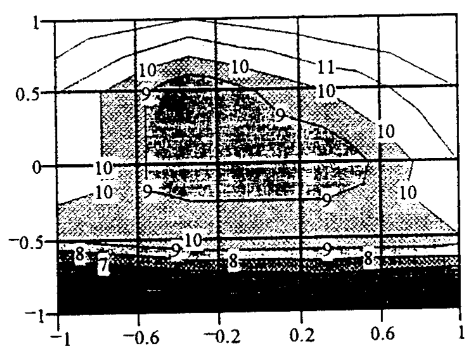
Soil Substrate "Moisture" Contour Plots - Seed Plots 1-4 (28 JUN 95)



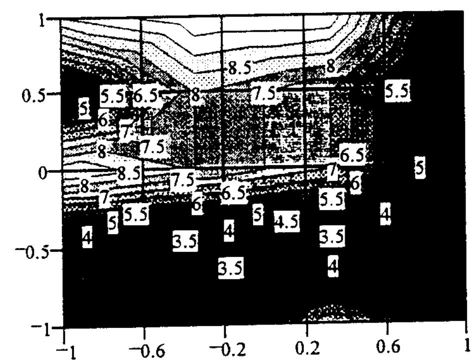
Soilseedplot1



Soilseedplot3



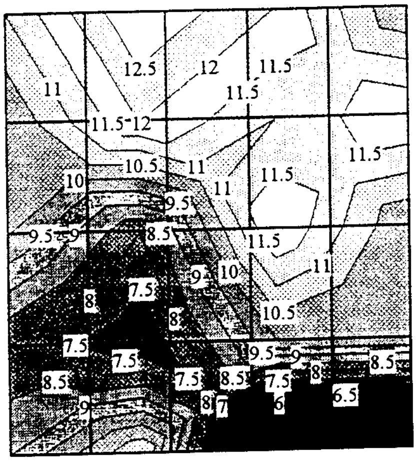
Soilseedplot2



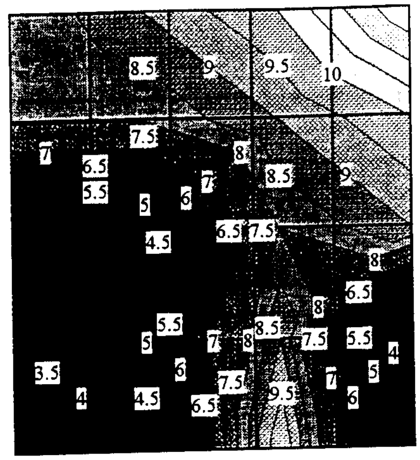
Soilseedplot4

Appendix N -- Water/"Moisture" Contour Plots

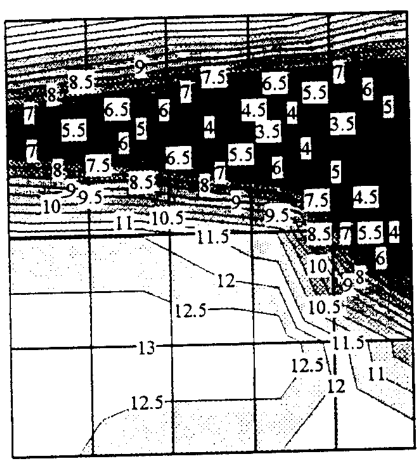
Soil Substrate "Moisture" Contour Plots: Greenhouse Plots 1-4 (28 Jun 95)



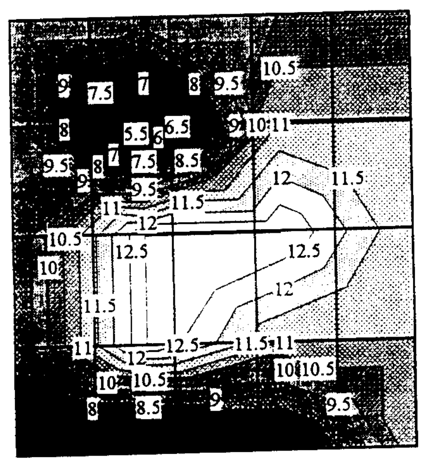
Soilgreenhsplot1



Soilgreenhsplot3



Soilgreenhsplot2



Soilgreenhsplot4

13 Driest
1 Wettest - Standing Water

Appendix N -- Water/"Moisture" Contour Plots

$$Soilseedplot1 := \begin{bmatrix} 10 & 12 & 12 & 13 & 10 \\ 7 & 11 & 11 & 10 & 9 \\ 5 & 11 & 11 & 10 & 13 \\ 10 & 11 & 11 & 9 & 13 \end{bmatrix}$$

$$Soilgreenhsplot1 := \begin{bmatrix} 9 & 8 & 10 & 10 & 11 \\ 11 & 7 & 8 & 12 & 13 \\ 3 & 10 & 12 & 11 & 12 \\ 3 & 10 & 10 & 12 & 10 \end{bmatrix}$$

$$Soilseedplot2 := \begin{bmatrix} 2 & 9 & 11 & 11 & 13 \\ 3 & 10 & 8 & 8 & 12 \\ 4 & 10 & 8 & 10 & 13 \\ 3 & 10 & 11 & 12 & 13 \end{bmatrix}$$

$$Soilgreenhsplot2 := \begin{bmatrix} 13 & 13 & 12 & 6 & 13 \\ 12 & 13 & 12 & 5 & 12 \\ 12 & 13 & 11 & 3 & 12 \\ 12 & 10 & 3 & 4 & 10 \end{bmatrix}$$

$$Soilseedplot3 := \begin{bmatrix} 3 & 6 & 8 & 10 & 10 \\ 4 & 6 & 6 & 6 & 10 \\ 5 & 6 & 5 & 3 & 10 \\ 2 & 6 & 3 & 3 & 10 \end{bmatrix}$$

$$Soilgreenhsplot3 := \begin{bmatrix} 4 & 3 & 4 & 8 & 8 \\ 4 & 5 & 4 & 8 & 9 \\ 10 & 9 & 8 & 9 & 10 \\ 3 & 3 & 9 & 10 & 12 \end{bmatrix}$$

$$Soilseedplot4 := \begin{bmatrix} 5 & 3 & 9 & 4 & 9 \\ 3 & 3 & 8 & 8 & 10 \\ 7 & 3 & 7 & 7 & 10 \\ 4 & 3 & 4 & 4 & 4 \end{bmatrix}$$

$$Soilgreenhsplot4 := \begin{bmatrix} 7 & 9 & 9 & 10 & 10 \\ 5 & 13 & 13 & 5 & 10 \\ 7 & 11 & 13 & 11 & 10 \\ 11 & 11 & 11 & 11 & 10 \end{bmatrix}$$

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Under the Clean Water Act Section 404 of 1972 and 33 CFR 320-330 and 40 CFR 230 moderate the destruction of wetlands by the Air Force to make way for other uses. To obtain a permit for a design or construction project which affects a wetland, the Air Force must agree to create new wetlands, or replace lost wetland acreage through wetland creation or restoration. The Air Force is interested in building "successful" wetlands as inexpensively as possible. It has been common practice to use hydric soil, which often had to be hauled in, as the substrate at the restored site to ensure vegetative success of the site. However, this project constructed a fen (wetland) 32m x 15.5m to experimentally compare the impact on vegetation of unsorted gravel till substrate versus hydric soil substrate. A fen is a groundwater driven wetland with a circumneutral pH and little to no standing water. Initial indicate that the hydric soil did better support vegetation, but the gravel substrate was functional. The vegetation on the gravel substrate is expected to catch up to that on the soil substrate in time.

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